UNIVERSITY of TASMANIA

A biogeography of Tasmanian coastal saltmarshes

by

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BSc (Honours)

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Degree of Doctor of Philosophy (PhD)
in the Discipline of Geography and Spatial Sciences,
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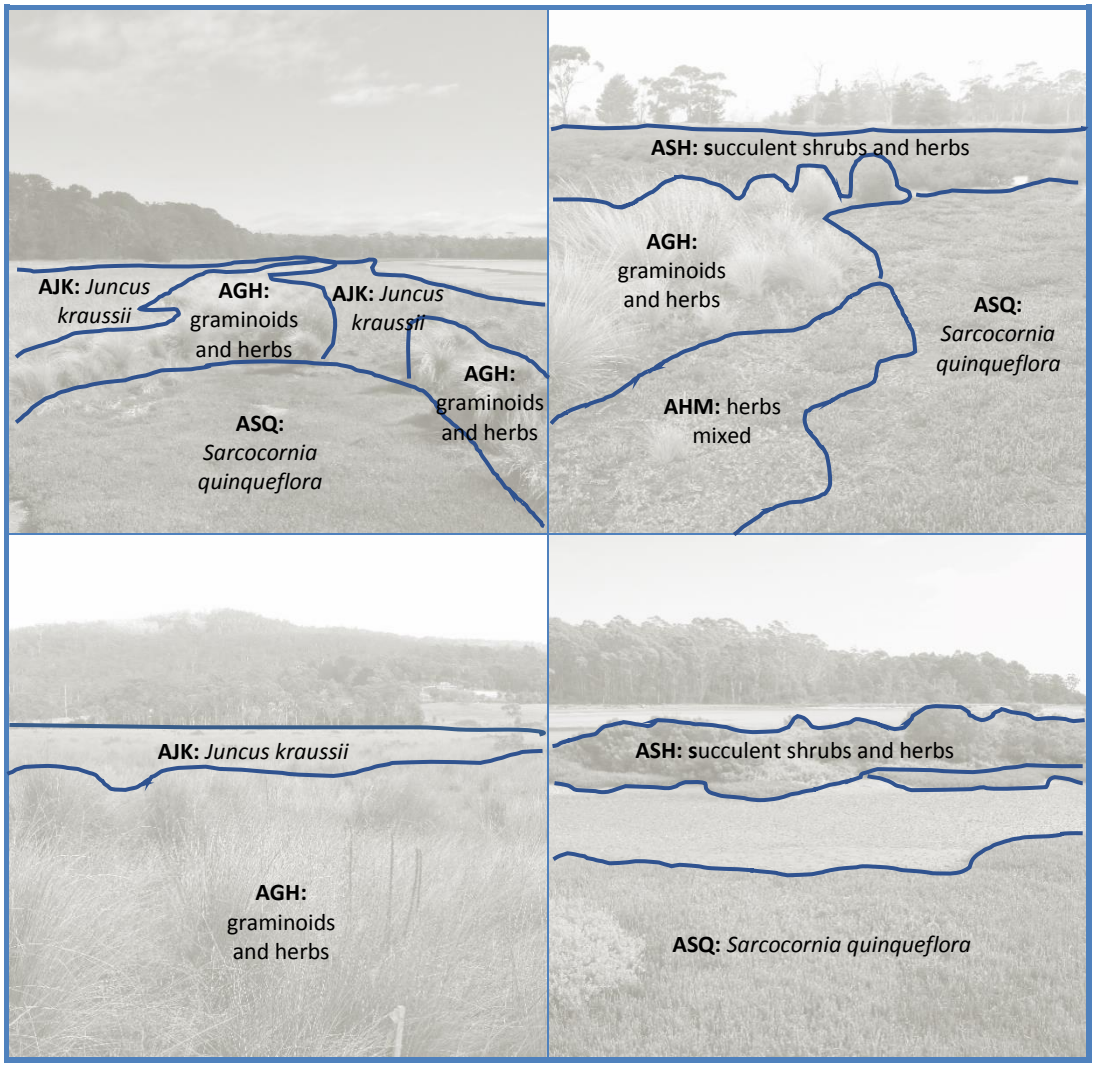
Cover image: Examples of saltmarsh vegetation patterning.



Top left: Cloudy Bay Lagoon, Bruny Island; **Top right:** 5-mile Beach, Llanherne**; Bottom left:** Hastings Bay (off Tongue Road, Hastings); **Bottom right:** Lutregala Marsh, Bruny Island.

The three letter alpha code (e.g. AGH, ASQ) refers to sperate vegetation communities as classified in Chapter 3.

Declaration of Originality

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

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Date: 15 July 2019

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Acknowledgements

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Special thanks and appreciation goes to all landowners who granted permission to either access their land to adjacent coastal marshes or those who owned coastal marshes. This study relied on their generosity. Individual landowners have been acknowledged in Chapter 2.

Similarly, field assistance from many persons was valuable. Many times, we bashed our way through hinterland shrub, crossed tidal flats, often knee deep in mud, navigated rivers and creeks, with water to mid-waist in depth. Carrying loads of soil samples was at time arduous. But we managed! Individual persons have been acknowledged in appropriate chapters, Chapter 3, 4 and 7.

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Unless otherwise acknowledged, all images are by the author.

Chapter table of contents

Note: Each individual chapter includes a table of contents and acknowledgements. A general table of contents has been included here. An overall bibliography has not been incorporated at the end of the thesis as one is included within each chapter.

Preamble

Tasmania, the island state of Australia, presents a unique opportunity to study the biogeography of coastal saltmarshes. Although far smaller (68,400 km^2) than other Australian states (the next smallest is Victoria at 237,630 km^2), its position in the cool temperate zone (centred approximately 42^{o}S, 147^{o}E) provides an array of coastal landscapes in which many saltmarshes are present. Tasmania, known for its rich saltmarsh flora, has diverse physical environments, strong gradients of climate (wet + cold to dry + warm), soil and topography. Most saltmarsh sites are relatively accessible, except for those in the far SW, and four major offshore islands (King, Flinders, Maria and Bruny) all have saltmarshes providing for good comparisons. There is a noteworthy absence of mangroves species making it easier to view and research saltmarshes in its "purest forms" (all other Australia coastal jurisdictions commonly have mangroves associated with coastal saltmarshes). Tasmania has distinctive natural regionalisations, characteristic geological influences (west coast: mainly volcanic quartzite, east coast: mainly volcanic dolerite/granite), and following an increase in sea-level subsequent to the last glacial maximum, has been separated from the mainland of Australia for over 10,000 years.

This study is timely; coastal saltmarshes are under pressure from sea-level rise, fragmentation and coastal development, whether it is encroaching agriculture or urban. Local citizens are becoming more engaged in coastal conservation and are generally an untapped resource when it comes to data collection. However, data collection must be disciplined and should conform to a standard where it becomes useful now and in the future. Data from this study forms an excellent baseline for such initiatives, and methods developed, tested and used can be replicated for future use here in Tasmania and Australia wide.

The format of this thesis is based on the traditional chapter method. However, each chapter is self-contained, although connected to the previous and following chapters, providing a continuous thread through the thesis. Chapters 3 to 7 are each organised into the standard introduction, methods, results and discussion, conclusion and bibliography. Chapters 1 (Introduction) and 2 (Definition) set the scene of the thesis, while Chapter 8 provides a synthesis and conclusion. Chapter 3 details the development of a fine scale vegetation community classification and attempts at aligning this to

pre-determined natural regionalisations; Chapter 4 investigates the complexities of saltmarsh soils and aligns previously classified vegetation communities to soil types; Chapter 5 determines soil carbon stocks using analytical methods; while Chapter 6 examines individual plant species tolerance ranges to soil and climate variables, and finally Chapter 7 tests key plant species resilience to differing salinity treatments in an open field trial. To provide the reader with a clear appreciation of the thesis structure and sub-studies within the main study, a roadmap (flowchart) of thesis chapters is presented in Figure P.1.

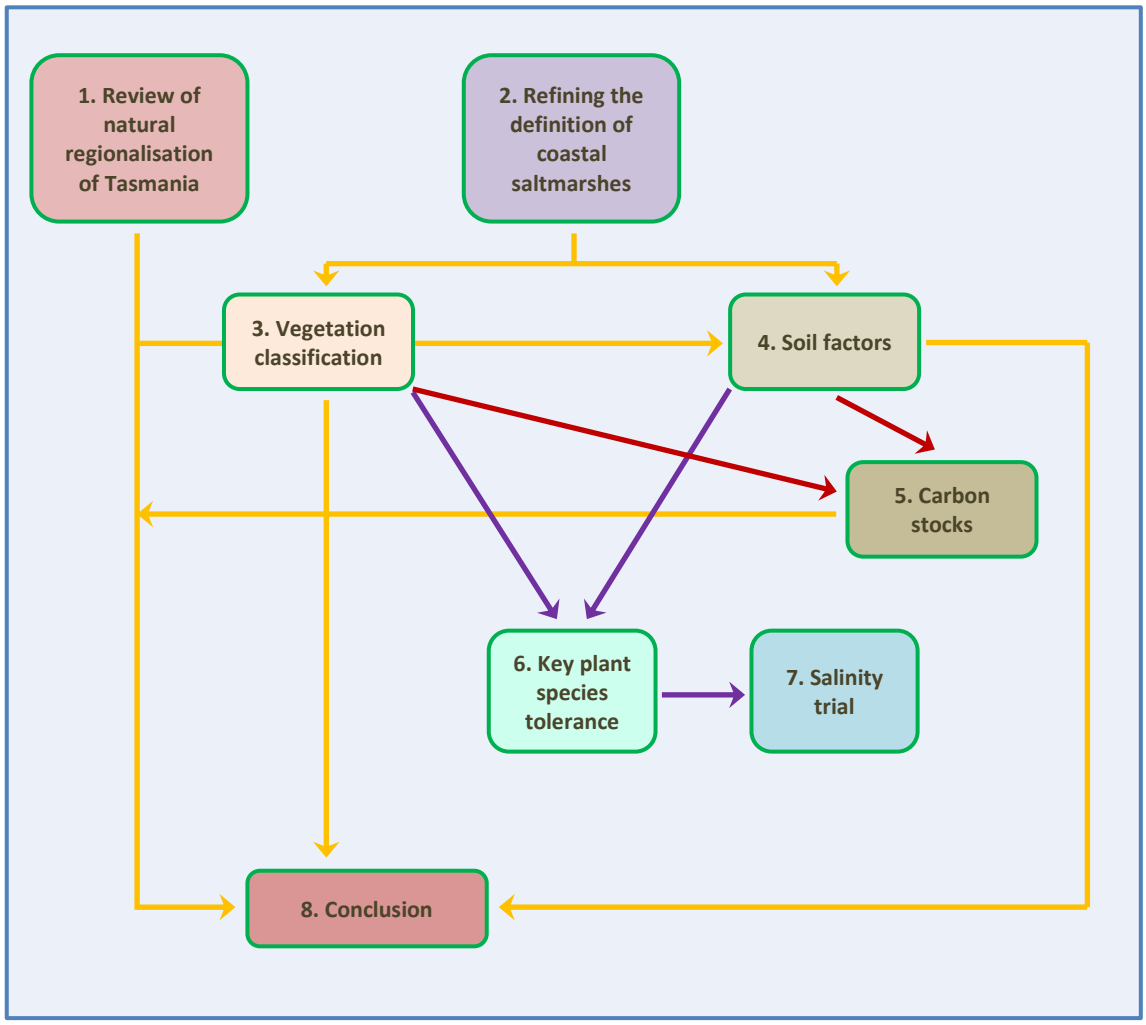

Figure P.1: Roadmap of thesis chapters (box numbers refer to chapter numbers).
Flow lines: → = main thrust of study; → = soil carbon stocks (adjunct study 1); → = plant species resilience (adjunct study 2).

The individual chapter approach was taken as it has given the author an opportunity to explore and justify suitable analyses, and to provide the reader with a deeper insight to Tasmanian coastal saltmarshes and their position in the landscape. The individual

chapters will also make it easier to publish many of the results from this study in the future.

Five sets of data (Table P.1) generated and used in this study are available and stored at https://www.dropbox.com/sh/zmxdoo70jlj8a4s/AAAQC8z90zSQiB-s3Hrs0EoGa?dl=0.

Table P.1: Details of data generated and used in this study available by link above.

Dataset	Chapter	Details
Combined dataset FINAL.xlsx	3, 4, 6	Complete dataset of all plots, vegetation group, plant species, edaphic factors, climate variables, regionalisation and regions.
PreliminarySites_LOI and Carbon FINAL.xlsx	5	LOI and total carbon data for Preliminary sites.
LOI conversions & TC FINAL.xlsx	5	LOI values for all plots, applied conversions from various sources and conversions from this study.
SalinityTrial dataset 1 FINAL.xlsx	7	Soil and applied water chemistry (pH and EC), rainfall.
SalinityTrial dataset 2 FINAL.xlsx	7	Plant species chemistry (pH and EC).

Glossary and abbreviations

Note: the words Location, Site, Transect and Plot, each described below, are key terms used in this study.

AHS: TASVEG 3.0[1] code for saline aquatic herbland.

ARS: TASVEG 3.0 code for saltmarsh vegetation community dominated by saline graminoids.

ASS: TASVEG 3.0 code for saltmarsh vegetation community dominated by saline succulents.

AUS: TASVEG 3.0 code for undifferentiated saltmarsh vegetation community.

AVH: Australian Virtual Herbarium.

AWU: TASVEG 3.0 code for undifferentiated wetland vegetation community.

BGS: Boags – a bioregion within IMCRA[1].

BOM: Bureau of Meteorology, an Executive Agency of the Australian Government, its parent organisation is the Federal Department of Environment and Energy.

Braun-Blanquet: method of assessing vegetation presence and cover abundance that estimates the quantity of cover of each species in a community in one scale.

BRU: Bruny – an IMCRA bioregion.

CAR: comprehensive, adequate and representative system of protected areas.

Climate variables: a collection of climate characteristics used in this study; NB the term "variables" is used so not to confuse between other collective terms such as (edaphic) factors, (vegetation) community etc.

Cluster/Group: a vegetation community detected by multivariate analysis.

CV: coefficient of variation, is defined as the ratio of the standard deviation to the mean. It displays the degree of variability in relation to the mean of a series of values.

DAV: Davey – an IMCRA bioregion.

DC: dry combustion.

[1] Described below.

DPIPWE[2]: Department of Primary Industry, Parks, Water and Environment (Tasmanian Government).

DPIWE[3]: Department of Primary Industry, Water and Environment (Tasmanian Government).

dS/m: decisiemens per metre, a unit of measure of EC (see below).

EC: electrical conductivity.

Edaphic factors: soil-related variables, a component of research in this project. Variables include moisture, pH and EC, carbon and soil organic matter; NB the term "factors" is used so not to confuse between other collective terms such as (climate) variables, (vegetation) community etc.

EPBC Act: *Environment Protection and Biodiversity Conservation Act 1999*, Commonwealth legislation.

FLI: Flinders – and IMCRA bioregion.

FRA: Franklin – an IMCRA bioregion.

FRE: Freycinet – an IMCRA bioregion.

FUR: Furneaux – an IBRA[4] bioregion.

Furneaux: a sub-region of the IBRA 6.1 Flinders bioregion.

Halophilic: describes organisms capable of living in high concentrations of salt.

Halophyte: salt-tolerant plant.

ICOL: Intermittent closed and open lagoon.

IBRA: Interim Biogeographic Regionalisation for Australia (common abbreviation).

IBRA6.1: Interim Biogeographic Regionalisation for Australia, version 6.1, the version used in this study as the current version (IBRA7 – see below) does not properly reflect the biogeographic used in Tasmania.

IBRA7: Interim Biogeographic Regionalisation for Australia, version 7 (2012).

[2] Current abbreviation
[3] Previous abbreviation
[4] Described below

IMCRA3.3: Interim Marine and Coastal Regionalisation of Australia, version 3.3 (1998), a regionalisation of Australian in-shore (as opposed to off-shelf) waters.

IMCRA4.0: Integrated Marine and Coastal Regionalisation of Australia, version 4 (2006) – the product of Interim Marine and Coastal Regionalisation of Australia (IMCRA3.3 a marine regionalisation of inshore waters) and the National Marine Bioregionalisation (NMB) (a regionalisation of off-shelf waters).

IMCRATG: Interim Marine and Coastal Regionalisation of Australia Technical Group.

Indicator species: species whose status provides information on the overall makeup and condition of the ecosystem and of other species in that ecosystem.

Intertidal: the zone/environment between the level of high and low tide.

Inundation: the condition of water occurring above the ground surface because of flooding by tidal waters or high precipitation.

KIN: King – an IBRA bioregion.

Location: Tasmania – state-wide, including coastal/offshore (Maria and Bruny) and Bass Strait islands (King and Flinders).

LOI: loss on ignition. A method used to estimate the organic matter content in soils.

LOI550: loss on ignition at 550^{o}C.

LOI850: loss on ignition at 850^{o}C.

NMB: National Marine Bioregionalisation – a regionalisation of Australian off-shelf (as opposed to in-shore) waters.

NRM: Natural Resource Management.

OTW: Otway – an IMCRA bioregion.

pH: a scale that measures how acidic or basic a substance is. It ranges from 0 to 14; solutions with a pH of 7.0 are neutral, less than 7 are acidic, and greater than 7 are basic or alkaline.

Phase 1: the initial round of vegetation assessments and design of a preliminary vegetation community key using Training sites[5].

[5] Described below.

Phase 2: the second round of vegetation assessments using the preliminary vegetation key and improvement of the key using Test 1 sites[6].

Phase 3: the third round of vegetation assessments using the improved vegetation key and development of a final key using Test 2 sites[6].

Plot: a position/point (measuring 2 x 2 metres) within a vegetation community used for data collection.

Preliminary sites: a research round of sites to test vegetation and soil assessment methods and analysis pre-Phase 1.

Range: a term used to describe the minimum and maximum values (the limits) of an observation.

Saltmarsh: tract of land tidally connected to the sea, covered with emergent, herbaceous, halophytic vegetation. The term saltmarsh in a Tasmanian context defined in Chapter 2.

SBD: soil bulk density.

Site: individual saltmarshes in each of Tasmania's six coastal bioregions.

Spread: a term used to describe the difference (maximum value less minimum value) between the limits of an observation.

Soil composition: the proportion of peat, sand, clay, loamy-soil and roots in a soil sample.

SOM: soil organic matter.

Spring tide/king tide: tide that is greater than the mean tidal range – occurs about every two weeks, when the moon is new or full.

SSZ: TASVEG 3.0 code for spray zone coastal complex vegetation community.

Sub-tidal: permanently below the level of low tide, an underwater environment.

[6] Described below.

TASVEG 3.0: a comprehensive digital map of Tasmania's vegetation produced by the Tasmanian Vegetation Monitoring and Mapping Program (TVMMP). Each vegetation community is assigned a three-letter code that defines the dominant vegetation community present within each polygon. TASVEG 3.0 is the current version.

Test 1 sites: the second tranche of sites used to test the draft vegetation community key to identify field use issues.

Test 2 sites: the third tranche of sites used to test the proposed vegetation community key (that derived from improvements following trials on Test 1 sites) to identify field use issues and from this complete the final key.

TLC: Tasmanian Land Conservancy (a not-for-profit, apolitical, science and community-based organisation that raises funds from the public to protect irreplaceable sites and rare ecosystems by buying and managing private land in Tasmania.

TNRMA: *Tasmanian Natural Resource Management Act 2002*.

TNS: Tasmania Northern Slopes – an IBRA bioregion.

Training sites: the initial sites used to develop a draft vegetation community identification key.

Transect: a line crossing individual saltmarshes (sites) generally laid to cross a number of different vegetation patches.

TSE: Tasmania South East – an IBRA bioregion.

TSR: Tasmania Southern Ranges – an IBRA bioregion.

TWE: Tasmania West – an IBRA bioregion.

Vegetation community: a collection of plant species growing together in a particular location that show a definite association or affinity with each other. A component of research interest in this study.

Vegetation community code: alpha code (used in this study) based on TASVEG 3.0 vegetation codes.

Plant species

Plant species are detailed as either dicot or monocot, then listed by family; individual species identified by scientific name (bold and italics) as per de Salas and Baker (2018), identifier code used in statistical analysis, and common name as per Wapstra *et al.* (2010) and Prahalad (2014). In several instances no identifier code is provided as the species has not been used in any analysis.

A standard format in the naming of plant species is used throughout this work. As each chapter is stand alone, the genus/species name is presented in full (e.g. *Sarcocornia quinqueflora*) at the first instance within the chapter. In subsequent occurrences within the chapter, the genus is shortened to the first alpha metric with the species name in full (e.g. *S. quinqueflora*). If there appears any possibility of confusion or conflict with other species names, the full naming format will be used. The use of the code identifier, which has been used in statistical analysis (for example, sar_qui), will be restricted, however, it is used in describing diagrams from statistical analysis.

Note: within the following [i] (preceding the species name) = introduced.

Dicots

Aizoaceae

Carpobrotus rossii (Haw.) Schwantes	Car_ros	Native pigface
Disphyma crassifolium (L.) L.Bolus subsp. ***clavellatum*** (Haw.) Chinnock	Dis_Cra	Roundleaf pigface
Tetragonia implexicoma (Miq.) Hook.f.	Tet_imp	Bower spinach

Amaranthaceae

Hemichroa pentandra R.Br.	Hem_pen	Trailing saltstar

Apiaceae

Apium prostratum Labill. ex Vent. subsp. ***prostratum*** var. ***prostratum***	Api_pro	Slender sea-celery
Eryngium vesiculosum Labill.	Ery_ves	Prickfoot
Lilaeopsis polyantha (Gand.) H.Eichler	Lil_pol	Jointed swampstalks

Asteraceae

Angianthus preissianus (Steetz) Benth.	Ang_pre	Salt cupflower
Brachyscome graminea (Labill.) F.Muell.	Bra_gra	Grass daisy
Cotula coronopifolia L.	Cot_cor	Water buttons
Leptinella longipes Hook.f.	Lep_lon	Coast buttons
Leptinella reptans (Benth.) D.G.Lloyd & C.J.Webb	Lep_rep	Creeping buttons
[i] ***Vellereophyton dealbatum*** (Thunb.) Hilliard & B.L.Burtt	Vel_dea	White cudweed

Campanulaceae

Lobelia anceps L.f.	Lob_anc	Angled lobelia
Lobelia irrigua R.Br.	Lob_irr	Salt pratia

Caryophyllaseae

Spergularia tasmanica (Kindb.) L.G.Adams	Spe_tas	Greater seaspurrey

Chenopdiaceae

Atriplex cinerea Poir.	Atr_cin	Grey saltbush
Atriplex paludosa R.Br. subsp. ***paludosa***	Atr_pal	Marsh saltbush
[i] ***Atriplex prostrata*** Boucher ex DC.	Atr_pro	Creeping orache
[?i] ***Chenopodium glaucum*** L.	Che_gla	Pale goosefoot
Sarcocornia blackiana (Ulbr.) A.J.Scott	Sar_bla	Thickhead glasswort
Sarcocornia quinqueflora (Bunge ex Ung.-Sternb.) A.J.Scott subsp. ***quinqueflora***	Sar_qui	Beaded glasswort
Sarcocornia quinqueflora (Bunge ex Ung.-Sternb.) A.J.Scott subsp. ***tasmanica*** Paul G.Wilson	Sar_qui	
Suaeda australis (R.Br.) Moq.	Sua_aus	Austral seablite
Tecticornia arbuscula (R.Br.) K.A.Sheph. & Paul G.Wilson	Tec_arb	Shrubby glasswort

Convulvulaceae

Wilsonia backhousei Hook.f.	Wil_bac	Narrowleaf wilsonia
Wilsonia humilis R.Br.	Wil_hum	Silky wilsonia
Wilsonia rotundifolia Hook.	Wil_rot	Roundleaf wilsonia

Euphorbiaceae		
[i] ***Euphorbia paralias*** L		Sea spurge
Goodeniaceae		
Selliera radicans Cav.	Sel_rad	Shiny swampmat
Malvaceae		
Lawrencia spicata Hook.	Law_spi	Candle saltmallow
Myoporacece		
Myoporum insulare R.Br.		Boobialla
Myrtaceae		
Eucalyptus obliqua L'Hér.		Stringy bark
Eucalyptus pulchella Desf.		White peppermint-gum
Plantaginaceae		
Plantago coronopus L. subsp. ***coronopus***	Pla_cor	Slender buckshorn plantain
Plumbaginaceae		
Limonium australe (R.Br.) Kuntze var. ***australe***	Lim_aus	Yellow sea-lavender
Limonium australe (R.Br.) Kuntze var. ***baudinii*** (Lincz.) A.M.Gray	Lim_aus	Tasmanian sea-lavender
Primulaceae		
Samolus repens (J.R.Forst. & G.Forst.) Pers. var. ***repens***	Sam_rep	Creeping brookweed
Scrophulariaceae		
Thyridia repens (R.Br.) W.R.Barker & Beardsley*	Mim_rep	Creeping monkeyflower

* Originally documented as *Mimulus repens*, altered in 2017 in the new version of "A census of the vascular plants of Tasmania, including Macquarie Island" following the usage in analysis in this study; Original code identifier (Mim_rep) retained.

Monocots

Cyperaceae

Baumea juncea (R.Br.) Palla	Bau_jun	Bare twigsedge
Ficinia nodosa (Rottb.) Goetgh., Muasya & D.A.Simpson	Fic_nod	Knobby clubsedge
Gahnia filum (Labill.) F.Muell.	Gah_fil	Chaffy sawsedge
Isolepis cernua (Vahl) Roem. & Schult.	Iso_cer	Nodding clubsedge
Schoenoplectus pungens (Vahl) Palla	Sch_pun	Sharp clubsedge
Schoenus nitens (R.Br.) Poir.	Sch_nit	Shiny bogsedge

Juncaeae

Juncus kraussii Hochst. subsp. ***australiensis*** (Buchenau) Snogerup	Jun_kra	Sea rush

Juncaginaceae

Triglochin striata Ruiz & Pav.	Tri_str	Streaked arrowgrass

Poaceae

Austrostipa stipoides (Hook.f.) S.W.L.Jacobs & J.Everett	Aus_sti	Coast speargrass
Distichlis distichophylla (Labill.) Fassett	Dis_dis	Australian saltgrass
Festuca arundinacea Schreb.	Fes_aru	Tall fescue
Lachnagrostis billardierei (R.Br.) Trin. subsp. ***billardierei***	Lac_bil	Coast blowngrass
Phragmites australis (Cav.) Trin. ex Steud.	Phr_aus	Southern reed
Poa labillardierei Steud. var. ***labillardierei***	Poa_lab	Silver tussockgrass
Puccinellia stricta (Hook.f.) C.H.Blom	Puc_str	Australian saltmarshgrass
[i] ***Spartina anglica*** C.E.Hubb		Rice grass
Zoysia macrantha Desv. subsp. ***walshii*** Night.	Zoy_mac	Prickly couch

Restionaceae

Apodasmia brownii (Hook.f.) B.G.Briggs & L.A.S.Johnson	Apo_bro	Coarse twinerush
Leptocarpus tenax (Labill.) R.Br.	Lep_ten	Slender twinerush

Xanthorrhoeaceae

Lomandra longifolia Labill.	Spiny-headed Mat-Rush

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de Salas, MF & Baker, ML (2018): *A census of the vascular plants of Tasmania, including Macquarie Island*. Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Hobart.

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Abstract

Visually, Tasmanian coastal saltmarshes appear to contrast greatly, both within and between sites, with a strong display of vegetation patterning. Some marshes can be dominated by saline graminoids or lawn-like herbaceous succulents, while others present a complex mosaic of plant species that thrive in the saline environment. A key question in our understanding of coastal wetland ecological features is whether mapped coastal saltmarsh reflects other biophysical patterns in the landscape. To this end, the historical and descriptive aspects of key Tasmanian natural regionalisations and domains are critically examined which focus on the terrestrial/maritime interface. Existing classifications including the Interim Biogeographic Regionalisation of Australia (IBRA), the Interim Marine and Coastal Regionalisation of Australia (IMCRA), weather forecasting districts, geographical position and a state-wide estuarine classification system were tested to their suitability in determining saltmarsh vegetation patterning.

From a Tasmanian perspective, the national definition of coastal saltmarshes has some shortcomings. Position in the landscape plays a key role in defining saltmarsh type and Tasmanian examples are examined to test their fit to National *(Environment Protection and Biodiversity Act, 1999)* and State (TASVEG) interpretations and guidelines. When sea-level rise and climate change ramifications are considered, a carefully measured and workable definition of Tasmanian coastal saltmarshes is derived that largely aligns with, but expands, the current guidelines.

Coastal saltmarshes in Tasmania display a range of vegetation configurations from multiple to single species communities. Tasmanian saltmarshes are historically classified to two vegetation classes, useful at a broad scale, but less effective at the fine scale required for ecological studies. A comprehensive state-wide (including off shore islands) vegetation assessment was carried out at 21 sites involving 110 plots. Multivariate analysis methods determined eight vegetation groups, and a diagnostic key to these was developed. Subsequently, the key was field tested on 70 sites (297 plots) and improved. The new vegetation community groupings were aligned to current vegetation classes, community indicator plant species were identified, and a typology produced that reflected each community, yielding a useful tool for future citizen science and management. The distribution of vegetation communities did not align at all with

most available natural regionalisations, but the national IMCRA classification provided a mediocre fit.

Field and laboratory analyses of bare ground cover, organic layer depth, pH, electrical conductivity (EC), moisture, bulk density, loss on ignition, and composition were carried out on soils from a state-wide collection of 407 coastal saltmarsh plots (91 sites). Multivariate analysis determined eight major soil types, yet, no clear alignment was identified with the vegetation communities. No individual or group of plant species could be exclusively aligned to a particular soil type. It was found that all eight vegetation communities were tolerant of wide ranges in most edaphic factors, but more constrained by climatic variables, such as temperature and rainfall. The distribution of saltmarsh soil types did not conform well with most natural regionalisations, although IMCRA showed modest alignment to soil type.

The soils of tidal wetlands are known to be important as carbon stores, however, few reliable estimates are available for Australian coastal saltmarshes and none for Tasmania. An extensive investigation reports in detail on carbon levels for Tasmanian coastal saltmarshes providing an accurate account of the quantum and distribution of this carbon store. Tasmania saltmarsh soils are found to be shallower on average than in other States, limiting the amount of stored carbon when compared to elsewhere in Australia. Tasmanian coastal saltmarshes contain a total carbon stock of 390,000 tonnes, currently valued at $19.8 million (AUD), with an average carbon offset value of $3,380 per hectare. Carbon content was found to vary two-fold across IMCRA bioregions. Limitations in current reporting were identified, and an improved protocol was proposed to account for common errors and uncertainties in carbon calculation.

The distribution of halophytes in coastal saltmarshes is believed to be determined by several abiotic factors such as tidal cycles, elevation and salinity. The state-wide vegetation and soil survey of coastal saltmarshes enabled the environmental ranges of key plant species to be classified in terms of EC (as a proxy for salinity), pH, moisture, organic matter, composition, temperature, rainfall and solar exposure. The key abiotic factors that played a role in species incidence were identified allowing decision tools to be produced as an aid in the appropriate selection of plant species suitable for saltmarsh restoration.

Rapid sea-level rise and climate change will threaten the integrity of coastal saltmarshes. The resilience of four key halophyte communities and their soils to pulses of increasing salinity (mimicking increasing sea-level) and decreasing salinity (mimicking increasing rainfall) was tested over a 16-month period. Key factors (electrical conductivity as a proxy for salinity, and pH) were measured at intervals in soils, and commencement and conclusion samples of four key plant species. Soils showed mostly unresponsive pH values across all treatments, with generally small changes of EC in increasing/ decreasing salinity plots, yet substantial increases of EC in the control plots. Changes within plant species were not a reflection of soil responses with pH and EC values increasing across all treatments. No plants died during the trial, further suggesting a level of resilience to changes in water conditions.

To conclude, the association between the eight vegetation communities, regionalisations and regions was at most unsystematic, although from a field-based view, IMCRA appeared to be somewhat appropriate. Similarly, saltmarsh soil types were not associated to any regionalisation, although again, IMCRA regionalisation was determined as a possible candidate. Carbon stocks differed between vegetation communities, but the differences were not significant. Carbon values for similar vegetation communities differed between regions of all regionalisations including IMCRA, suggesting no association between sequestered carbon and regionalisation. The strongest alignment of saltmarsh vegetation patterning appears to be with two climate variables, temperature and rainfall. This particularly relates to two climatic sectors, that of wet + cold, and dry + warm, with patterning association also evident between wet + warm, and cool + dry.

Key words/phrases

Saltmarsh, saltmarsh definition, natural regionalisation, vegetation communities, edaphic factors, carbon store, plant species tolerances, Tasmania

Chapter 1

Introduction: Regionalisation of Tasmanian natural areas

Chapter 1 – Table of contents

Chapter 1: Introduction: Regionalisation of Tasmanian natural areas

1.1 Coastal saltmarshes

It is well established that coastal saltmarshes are an endangered ecosystem (Adam 1990; Fairweather 1990; Saintilan 2009a; Boon 2011; Department of the Environment and Energy 2013), and in some areas research is lacking, especially in Tasmania (Prahalad & Kirkpatrick in press). Saltmarshes are under threat from climate change and sea-level rise (Laurance *et al.* 2011), as coastal squeeze will limit landward movement due to anthropogenic obstructions, such as urban and rural development. Not only do saltmarshes provide ecosystem services, such as, barriers to storm surges, fish habitat and effluent filtration, this endangered ecosystem is an integral part of the coastal food web, especially in relation to migratory birds (Hughes 2004; Laegdsgaard 2006; Boon 2011). When viewed in its entirety, from soils, plants, terrestrial and benthic invertebrates, the loss of these coastal ecosystems will severely impact the survival of seasonal birds (e.g. the Orange bellied Parrot) as their food source becomes diminished. Coastal saltmarsh protection, conservation and restoration is sorely warranted.

Historically, saltmarshes have been much despised as landscapes. Typically, they are flat, boggy, cold and damp, the source of biting insects such as midges and mosquitos, and often are a feature in horror stories (Bridgewater *et al.* 1981). Frequently regarded as wastelands, coastal saltmarshes, have become the domain of grazing and agriculture, coastal resorts, playing fields, and even refuse disposal sites (Kirkpatrick & Glasby 1981; Finlayson & Rea 1999; Saintilan 2009a). Notwithstanding the historical negative connotations and sustained abuse, saltmarshes are a distinctive and intriguing ecosystem that bridge the land-sea boundary (Bridgewater *et al.* 1981). Yet, this intertidal biome is one of the most restricted habitats in the world (Pétillon *et al.* 2008) covering less than 0.01% of the earth's surface (Desender & Maelfait 1999). Saltmarsh areas are increasingly being reduced from a raft of pressures such as soil pollution from adjacent agricultural lands (Pétillon *et al.* 2008), aquaculture, port extensions, introduced species and sea-level rise (Adam 2002; Laurance *et al.* 2011).

Although widespread and established on all continents except for Antarctica, saltmarshes are generally found between the Tropic of Cancer and the Arctic circle in

the Northern Hemisphere, and between the Tropic of Capricorn and latitude 60°S in the Southern Hemisphere (Chapman 1974). They are only found infrequently within the tropics, either being limited to areas not dominated by mangroves or interspersed with mangroves (Adam 2002).

Saltmarshes occupy sheltered coasts, particularly those in protected estuaries. They can be recognised by their distinctive vegetation communities ranging from saline graminoids to saline succulents and are often located in areas inundated by tidal influences (Long & Mason 1983; Adam 1990, 2009). Many estuarine saltmarshes have distinguishing features such as conspicuous zonation, the delineation of the marsh into low, middle and upper zones defined by vegetation.

On a global scale it is difficult to estimate, let alone measure, the extent of saltmarshes. An estimation is made more difficult by the question of definition given that the US data includes brackish marshes, whereas Canada excludes these areas, and in Europe, though extensively studied, saltmarsh area data are not available (Adam 2002). Chapman (1974) estimates that the east and west coasts of the North American continent are home to the most extensive areas of saltmarshes followed by the north, western and Mediterranean coasts of Europe.

Recent efforts to determine the global area of saltmarshes estimated a range of 2.2 to 40 million hectares (Pendleton *et al.* 2012). In an attempt to narrow this large range, Mcowen *et al.* (2017, p. 8) composed a dataset "derived from peer-reviewed articles and grey literature, including reports and databases created by governmental and non-governmental agencies, universities, institutes and researchers globally". New estimates equated to 5.5 million hectares, this at the low end of the previous estimate (Mcowen *et al.* 2017).

Australia, by global standards, has only a small proportion of its coastline as saltmarsh ecosystems which cover approximately 1.6 million hectares (Saintilan & Adam 2009), though recently, this figure has been revised downwards to 1.33 million hectares (Mcowen *et al.* 2017). Australian saltmarshes are generally limited to the south east of the continent, including Tasmania, with small areas in the southwest of Western Australia (Chapman 1974) (Figure 1.1).

Tasmania has 5,860 hectares of coastal native wetlands (Prahalad & Kirkpatrick in press), principally located on its south-east and east coasts including Flinders Island, north coast and the far northwest of the State (Figure 1.2). Isolated pockets occur on King Island and the west coast of the State. In this context, native refers to those areas made up of native vegetation species as opposed to non-native, those areas made up of introduced/invasive species, for example, *Spartina anglica* (common cord-grass or rice grass), which is present in major infestations in the Tamar River and Port Sorell.

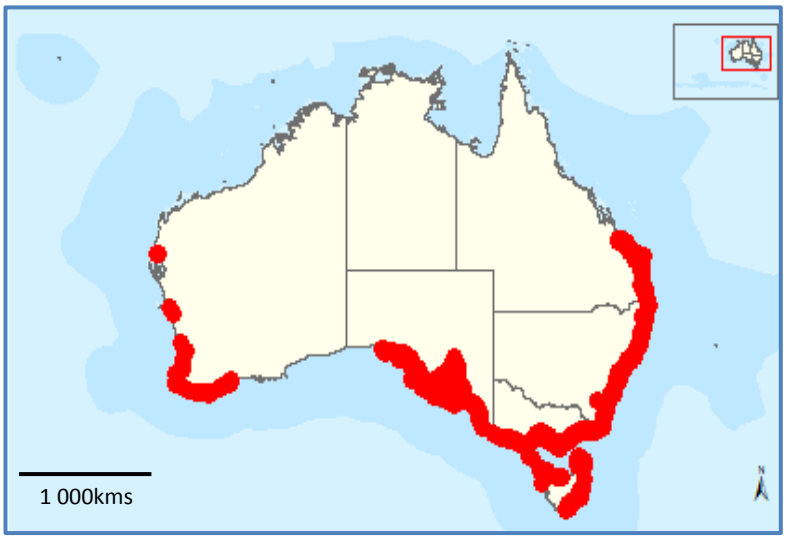

Figure 1.1: Distribution of Australian coastal saltmarshes. **Source:** Department of the Environment and Energy (2017).

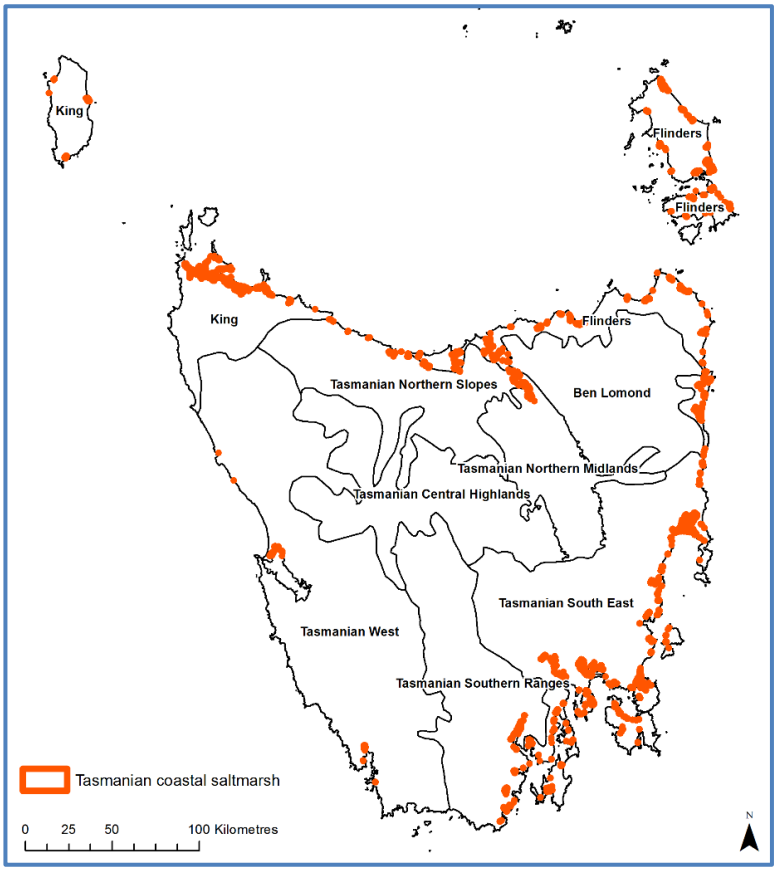

Figure 1.2: Tasmanian coastal saltmarshes (map based on IBRA7 bioregions). **Source:** courtesy V Prahalad (2018).

Visually, Tasmanian coastal saltmarshes appear to vary greatly, both within and between sites with a strong evidence of patterning. Some marshes are dominated by saline graminoids (particularly rushes) or by lawn-like herbs (particularly succulents), while others display a complex mosaic of plant species that are ideally suited to the saline environment. Often these differences can be quite stark – a section of a marsh totally dominated by an individual tall plant species, yet in another section, often close by, a verdant succulent lawn – while at other times, differences can be very subtle – a mix of tall plants interwoven with an array of groundcover herbs (Figures 1.3 to 1.5). Thus, begs the question: Can differences within and between saltmarshes be put into regions based on biotic attributes, such as plant species (or vegetation communities), and abiotic attributes, such as soil (edaphic) factors, climatic variables (e.g. temperature and rainfall) or geomorphic characteristics, such as catchment area?

Figure 1.3: Mixed coastal saltmarsh – *Austrostipa stipoides*, *Suaeda australis* (both foreground), *Tecticornia arbuscula* (background), *Lawrencia stricta* and *Sarcocornia* spp. (as ground cover).

Figure 1.4: Succulent herb "lawn" coastal saltmarsh – *Sarcocornia quinqueflora* and *Sarcocornia blackiana* with saline grassland in the background (see right).

Figure 1.5: Tall saline grasses coastal saltmarsh – *Juncus kraussii, Gahnia filum* and *Austrostipa stipoides*.

1.2 Natural regionalisation and legislation

Distinguishing regions of a state/country can take many configurations: simple – individual state jurisdictions, telephone districts, weather forecast districts – and complex – herbarium (collection) regions, local municipal council areas. Obviously, some classifications of regions, for example, state boundaries, are unhelpful in a biogeographic sense as living forms are not defined or constrained by them. In the case of coastal saltmarshes, an ecological system, it would be prudent to consider biogeographical boundaries. However, saltmarshes are often considered to be a fringe ecosystem – the area between the terrestrial and marine environments – an ecosystem that cannot, or should not, be defined by just a terrestrial or marine based framework alone. Consideration should then be made on several natural regionalisations before resolving the best fit for use.

Natural regionalisation

Natural regions of Australia can be identified/classified in several ways:

- Weather forecast districts – marine and land;
- Estuarine classification;
- Geographically;
- Botanically (herbarium and floristics);
- Nature conservation areas;
- Biogeographically;
- National reserves system (such as, National Parks, Conservation Areas); and
- Marine protected areas (e.g. Great Barrier Reef Marine Park, Commonwealth Marine Reserves, Tasmanian Marine Reserves).

Legislation

Legislation covering natural regions include:

- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999) (Commonwealth);
- *National Parks and Reserves Management Act 2002* (Tasmania);

- *Nature Conservation Act 2002* (Tasmania); and
- *Tasmanian Natural Resource Management Act 2002*.

1.2.1 Where do Australian coastal saltmarshes fit?

Coastal saltmarshes exhibit a unique ecological structure and are the interface between the terrestrial and marine environments. Because of their place in the environmental landscape, saltmarsh ecological studies are at times limited, possibly due to lack of interest or research investment. Maybe saltmarsh research is deemed uninteresting, especially when compared to attractive terrestrial and/or marine based studies, (Boon 2011).

As saltmarshes do not appear to fit in either the terrestrial or marine environments, one must choose which represents "the best ecological fit" in terms of regionalisation of a terrestrial and estuarine/inshore environment (as a combined unit) on a national (all Australian) basis. From the options presented above, weather forecast regionalisation is based on Bureau of Meteorology (BOM) land and coastal forecast districts, thus incorporating aspects such as temperature and rainfall, useful attributes that can delineate regions in the landscape; estuarine classification is a matter of applying physical attributes, such as estuary type (e.g. barred or open), tidal range, salinity and runoff, to locations and subsequently grouping similar locations by common attributes; botanical (herbarium and floristics) regionalisation based on vegetation type, often a broad brush approach, (e.g. rainforest, closed forest, grasslands); biogeographical options include: Interim Biogeographic Regionalisation for Australia (IBRA, current version 7), which represents the landmass bioregionalisation of the Australian continent, including off-shore islands, (e.g. Macquarie Island, Lord Howe Island); and the Interim Marine and Coastal Regionalisation of Australia (IMCRA, current version 3.3), representing the marine bioregionalisation of inshore waters; and nature conservation regionalisations, these based on protected/conserved areas or production areas, such as farming or forestry.

1.2.2 Where do Tasmanian coastal saltmarshes fit?

Each of the following regionalisations presented below, may be a suitable candidate that could adequately describe the diversity of Tasmanian coastal saltmarsh vegetation communities. The regionalisations are presented with the appropriate Tasmanian

coastal regions (inland regions have been excluded). Note: herbarium (including vegetation and floristics) and nature conservation regionalisations (Orchard 1988) have been examined in the section on IBRA.

1.3 Weather forecast districts

Forecast districts[7] have been delineated by the BOM to facilitate better localised weather forecasting and reporting for land districts and marine zones (Figure 1.6, following page). Delineation of land districts has been based on historical data, rainfall regions and major catchments, with a partially subjective approach of combining areas that have similar weather patterns and meeting community expectations, the latest update being 1995. Coastal districts are bounded by reference points, these being prominent geo markers along the Tasmanian coast (e.g. the Central West Coast district bounded by Sandy Cape and Low Rocky Point), where onshore weather patterns are similar in each district. The districts are a consensus position suitable for commercial fishers, this arrangement formalised during the 1990s.

A regionalisation based on weather attributes could be valuable, as temperature and rainfall may be useful indicators of plant species presence and absence within specific locations (Bertness & Ewanchuk 2002; Saintilan 2009b; Fariña *et al.* 2018).

[7] Follows: Ian Barnes-Keoghan (BOM Climatologist) (personal communication, May 2018).

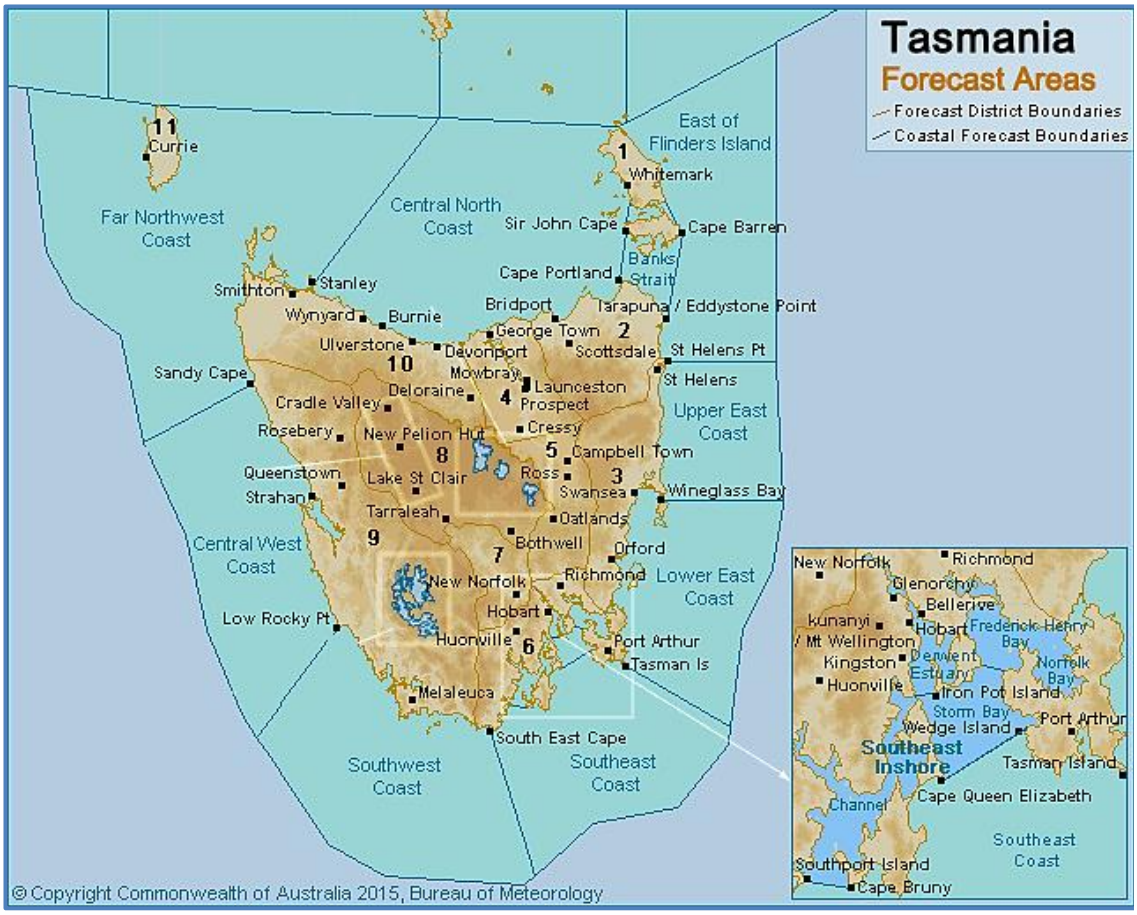

Figure 1.6: Tasmanian forecast areas. **Source:** BOM (2017).

Land district with a coastal border: 1 – Furneaux Islands; 2 – North East; 3 – East Coast; 6 – South East; 9 – Western; 10 – North West; 11 – King.

Coastal marine areas (9) are named in light blue (on map), encompass the State and King and Flinders islands.

1.4 Estuarine classification

Various physical attributes have been studied to account for saltmarsh distribution and patterning that occurs within and between marshes (Long & Mason 1983; Adam 1990; Pennings *et al.* 2003; Crain *et al.* 2004; Kunza & Pennings 2008). In a Tasmanian context, the study by Edgar *et al.* (1995) on microbenthic invertebrate species production and abundance, identified nine groups, however sizeable variations were found between invertebrate fauna within estuaries, particularly those described as drowned river valleys and marine inlets.

A further study by Edgar *et al.* (2000) examined a number of physical attributes, such as catchment size, estuarine drainage size, estuarine perimeter length, summer and winter salinity, and the presence or otherwise of a seaward barrier, and classified estuaries state-wide (n = 111) to nine groups. Two groups contained one estuary each, group VI

(Tamar River), and group IX (Wanderer River), while the remaining seven groups ranged from four estuaries to 29 estuaries per group. Not all classified estuaries contained coastal saltmarsh habitats. Most estuaries in the South and West regions are depauperate being subject to extreme weather conditions, such as strong wave action, storm surges, high rainfall and cold, often for long periods. Numerous southern and western estuaries are also subject to very low concentrations of dissolved nutrients and are rich in dark tannin-stained water that inhibit algal photosynthesis resulting in very low productivity.

Estuary classification[8] yielded several insights; a) northern Tasmanian estuaries had greater tidal ranges and were all open to the sea compared to those on the east, south and west coasts; b) estuaries of the south, west and northwest were typified by higher rainfall and runoff; and c) Bass Strait island estuaries and those on the east coast were classed as intermittently closed and open lagoons (ICOLs) controlled by sand barriers.

From a coastal saltmarsh perspective, this method of regionalisation could be very effectual in terms of physical characteristics, as it provides information on geomorphology, geology and hydrology, important aspects in the establishment, growth and survival of coastal saltmarsh plants and development of vegetation communities.

1.5 Geographical regions

Edgar *et al.* (1999, p. 49) defined eight coastal regions (Figure 1.7, following page) subjectively based on geomorphological attributes and breaks in the coastal landscape (Edgar 2018), these named according to position on the coastline (Table 1.1, following page).

In terms of delineating coastal saltmarshes, geographical regions may be a suitable method as this examines, at a very broad scale, the location of each saltmarsh in the landscape. However, in this case, regional boundaries have been determined on a non-natural basis, this delineation being based on a subjective assessment of coastal geographical aspects.

[8] Follows: Edgar *et al.* (1999).

Figure 1.7: Eight broad based geographical coastal regions of Tasmania based on Edgar *et al.* (1999). Region breaks from NE corner of Tasmania: Great Musselroe Bay, Blackman Bay, Cockle Creek, Payne Bay (Port Davey), Arthur River, Welcome River and Tamar River. Both King and Flinders islands stand-alone.

Note: the large gap (far north of west coast) between West and Northwest regions (Cape Grim to Arthur River) – there are no estuaries on this section of coast.

Map source: DPIPWE (2014).

Table 1.1: Geographical regions adopted by Edgar *et al.* (1999) in the classification of Tasmanian estuaries. Region names follows Edgar *et al.* (1999). **Note:** boundaries begin and end at estuaries, in all cases boundaries do not abut, as there are no estuaries between region boundaries.

	Extent of Region	
Region	**From**	**To**
Furneaux	Includes all of Flinders and Cape Barren Island	
East	Great Musselroe Bay	Earlham Lagoon (Rheban)
Southeast	Blackman Bay (Dunalley)	Cockle Creek
South	South Cape Rivulet	Payne Bay
West	Mulcahy River	Arthur River
King	King Island	
Northwest	Welcome Inlet (east Woolnorth)	Port Sorell
East north	Tamar River	Little Musselroe Bay

1.6 Vegetation and floristic regions

A vegetation map[9] [10] of Tasmania, based on predominant vegetation of broad regions delineated to six groupings, was produced by Davies (1964) for the 1965 *Atlas of Tasmania* (Figure 1.8).

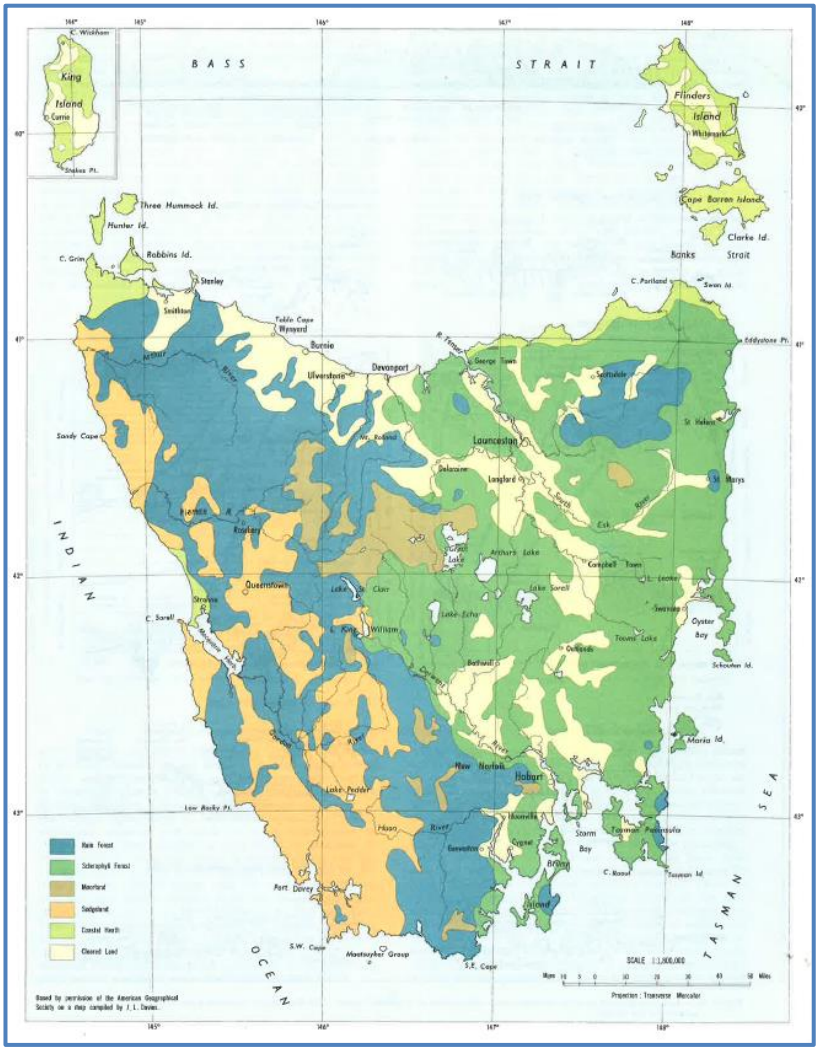

Figure 1.8: Vegetation regions of Tasmania used by Jackson for the *1965 Atlas of Tasmania*.
Source: Jackson (1965).
Note: the map is based on one by JL Davis prepared in 1964.
Map legend is included within figure (bottom left).

The main area of interest is the vegetation community Coastal Heath (coloured lime green on the map – Figure 1.8), this found mostly the Bass Strait islands (King and Flinders), the far northwest corner and the eastern side of the north coast and "…occur generally on coasts as a narrow belt of wind and salt limited vegetation on infertile soils…" (p. 30). The extensive areas of coastal saltmarsh on Tasmania's east coast are not indicated, this overshadowed by the vegetation community of Sclerophyll Forest. The text author, Jackson (1965), does admit the difficulty of producing vegetation

[9] Follows: Specht *et al.* (1974).
[10] Follows: Jackson (1974).

mapping based on floristic differences caused by altitude, aspect and soil types, as these local variations are often dwarfed by regional variations making it challenging to produce fine scale vegetation maps at this scale.

During the late 1960s and early 1970s, a major Australian/Papua New Guinean (A&PNG) study on the *Conservation of major plant communities in Australia and Papua New Guinea* (Specht *et al.* 1974) was conducted, this finalised in 1974 after seven years of work (Note: during the time of this study, Papua New Guinea was an external territory of Australia under an international trusteeship, hence that jurisdiction's inclusion in this work). The research was conducted by the Australian Academy of Science, under the auspices of the Terrestrial Conservation Section of the International Biological Programme, as part of its worldwide investigation into the preservation of significant ecosystems by means of parks and reserves. The A&PNG section of the international investigation was carried out in several sequential stages:

- The development of a simple classification of plant communities based on structural appearance;
- A survey of plant communities within established National Parks and Reserves;
- Compilation of a list of plant communities by State and Territory (including PNG) based on three categories: a) alliance[11]; b) association[12]; and c) society[13]; and
- An assessment of the conservation status of plant communities.

For this study, Tasmania was divided into floristic regions by Jackson (1965) (Figure 1. 9, following page). Sources such as Rodway (1903), Taylor (1955), Curtis (1956 - 67) and Townrow (1969), with vegetation assessments of then current parks and reserves by Jackson (1965), were used to determine the presence and conservation status of each alliance by floristic region.

[11] Alliance – a series of climax plant communities which have same structural characteristics, related dominant species in uppermost stratum, and possibly same or related species as understorey.
[12] Association – a series of climax plant communities which have same structural characteristics, same dominant species in uppermost stratum, and possibly different species as understorey.
[13] Society - a series of climax plant communities which have same structural characteristics, same dominant species in uppermost stratum, and same species as understorey.

Saltmarsh plant species, for example, *Arthrocnemum* (now *Tecticornia) arbuscula, Cotula coronopifolia* (an introduced species), *Disphyma australe* (now *D. crassifolium), Distichlis distichophylla, Leptocarpus* (now *Apodasmia) brownii, Salicornia* (now *Sarcocornia) quinqueflora, Samolus repens, Stipa* (now *Austrostipa) stipoides* and *Tetragonia implexicoma,* were recorded in several coastal National Parks and reserves such as Maria Island National Park and Freycinet National Park (region 9), Betsey Island (region 10), and the South West Fauna District (region 11).

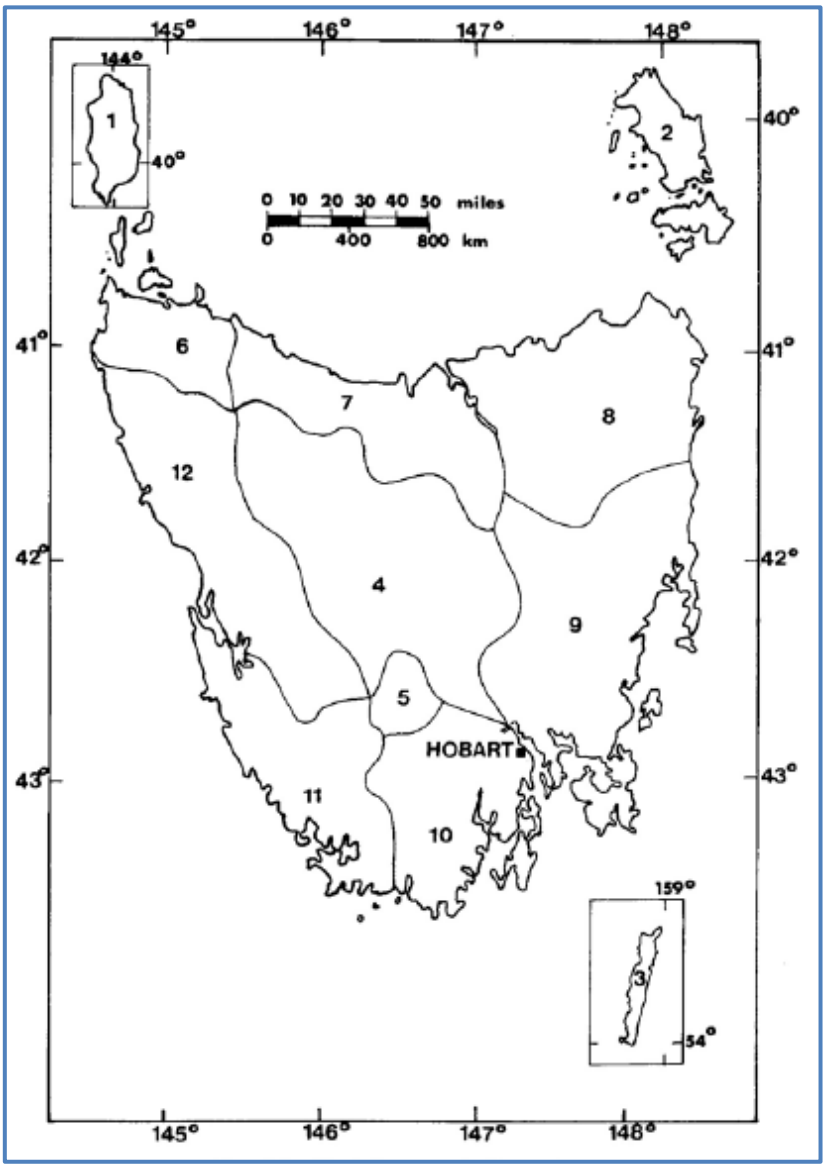

Figure 1.9: Floristic regions of Tasmania. Those applicable to this study – clockwise from 2 (top left):
2 = Flinders Island
8 = North East
9 = East
10 = South East
11 = South West
12 = West
6 = North West
1 = King Island
7 = North.
Note: Region 3 (Macquarie Island) is not part of this study.
Source: Jackson (1974).

1.7 IBRA

1.7.1 National IBRA bioregions

Background [14]

This section assembles from literature and personal communications, the historical development of the most important biogeographical regionalisation of Australia (and Tasmania), hence it is relatively expansive. Several of the following maps are of a poor resolution making some aspects within the maps illegible, unfortunately, better quality figures were unavailable.

The need for a national approach to Australia's protected areas was recognised during the late 1970s and 1980s, however, convincing individual States and Territories of the necessity of a national "ecological meaningful regionalisation" was generally unsuccessful. In 1992, the Commonwealth Government, in conjunction with State and Territories, provided funds to develop a comprehensive, adequate and representative (CAR) system of protected areas by the year 2000. Three continental regionalisations were initially considered by the Commonwealth Government: biophysical regions (Laut *et al.* 1975), environmental regions (Thackway & Cresswell 1992) (Figures 1.10 and 1.11, following page), and natural vegetation (Australian Surveying and Land Information Group (AUSLIG) 1990) (Figure 1.12, following page).

States and Territories responded that there was a need to develop a national biogeographic regionalisation primarily sourced from State and Territory data and information. It was deemed essential that any bioregionalisation be specific to the National Reserves System Cooperative Program (NRSCP), a Commonwealth Government (funded) initiative of a national comprehensive system of parks and reserves. Workshops and technical meetings involving all parties followed, and by July 1994, all participants approved that the final technical report, an "interim (my emphasis) biographic regionalisation for Australia" (IBRA), be made publicly available and its use implemented as originally intended.

On completion it was recognised that: "The IBRA represents a milestone product, meaningful to both field-based ecologists and land managers. It is acknowledged that validation of the regions is required and subsequent revisions necessary" (p. x).

[14] Follows: Thackway and Cresswell (1995).

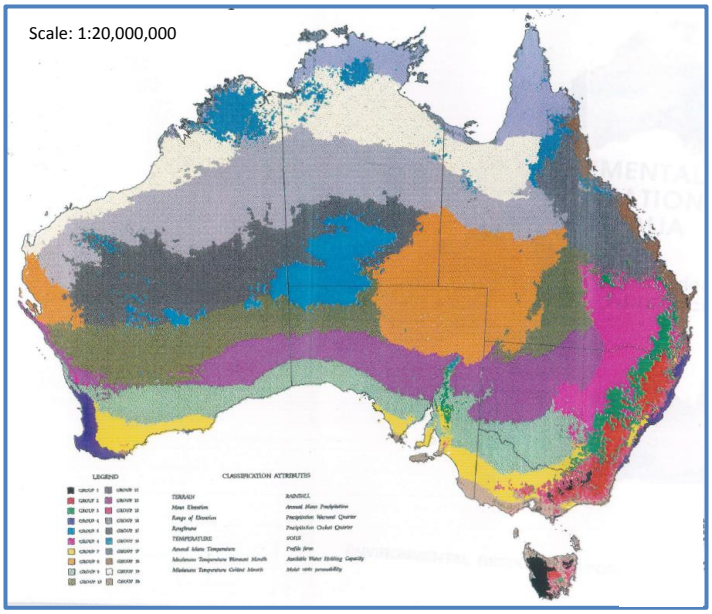

Figure 1.10: A twenty group environmental regionalisation of Australia. **Source:** Thackway and Cresswell (1992).

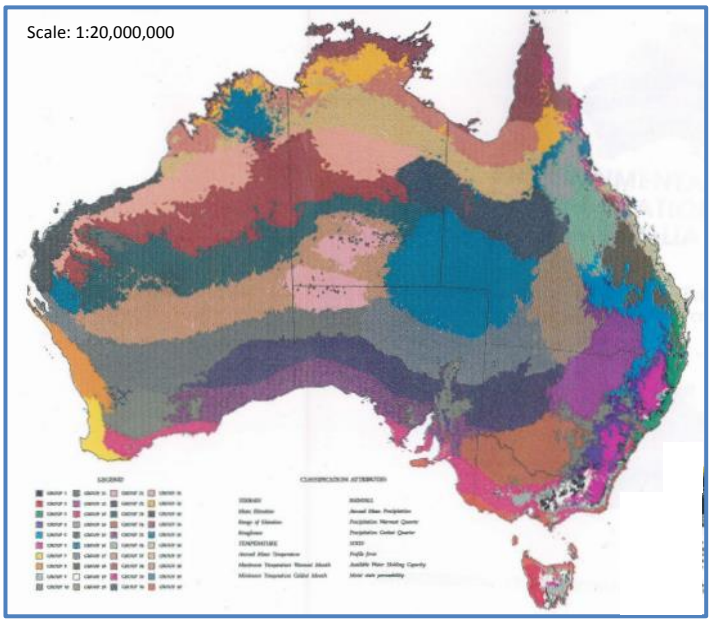

Figure 1.11: A forty group environmental regionalisation of Australia. **Source:** Thackway and Cresswell (1992).

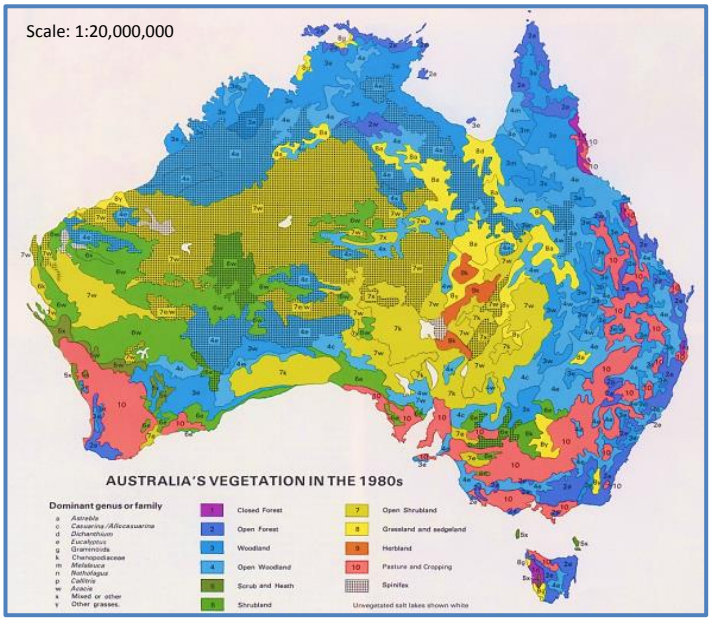

Figure 1.12: Australian natural vegetation regions. **Source:** AUSLIG (1990).

Nominal attributes for IBRA [15]

Major attributes used to delineate IBRA bioregion boundaries were climate, lithology/geology, landform, vegetation, flora and fauna and land use.

Each State and Territory provided the best available data, including field knowledge, environmental reports, local biogeographic regionalisations and any published resources. Datasets were provided as fine scale GIS, map unit boundaries as paper maps or drafting film; regions were aggregated where taxonomy and descriptions were known, jurisdiction boundaries were ignored. Existing common nomenclature and descriptions generated IBRA region names, cross-border regions names were revised to a more-meaningful term, and where no names were available, field knowledge was sourced to produce these. A series of internal versions of IBRA were produced and circulated for comment (Table 1.2).

Table 1.2: IBRA versions since inception (condensed), incorporating number of regions and sub-regions. **Sources:** Thackway and Cresswell (1995), Environment Australia (2000), Department of Environment and Energy (2016).

Version	Date	Regions	Subregions	Comments
Prior to IBRA		130		Existing bioregions across Australia, defined by State and Territory based nature conservation agencies across individual jurisdictions.
1.0 to 3.1	Feb-Apr, 1994			Development versions for internal use only.
3.2	1994	80		Widely circulated for discussion and comment.
3.3 and 3.4	Early-mid 1994			Internal versions; edits from comments received on version 3.2.
3.5	Jul, 1994			Prepared for discussion at Alice Springs technical meeting.
4.0	Mar, 1995	80		Public release and use within governmental and scientific communities.
5.0	Jul, 2000			Collation of new boundaries and resolution of anomalies.
5.1	Nov, 2000	85	354	Contains revisions made by States and Territories.
6.1	2005	85	403	Refine regional boundaries; extend regionalisation as additional data became available.
7.0	2012	89	419	Include four new oceanic regions – Pacific, Indian, Subantarctic and Coral Sea; naming and coding updated to more consistent format; updated region and sub-region boundaries in several jurisdictions, but not Tasmania.

[15] Follows: Thackway and Cresswell (1995).

Development of IBRA to version 4.0

Since the first technical meeting in Adelaide in 1994, IBRA has progressed through several versions, each updated from the previous. Improved mapping, new information, adjustment of boundaries, new protected areas added and corrections, all lead to revisions (Thackway & Cresswell 1995; Environment Australia 2000).

IBRA4.0 (1995) [16]

IBRA4.0 is a culmination of planning and technical meetings over a two-year period (1994/5). Previous versions – 1.0 to 3.2 – were circulated within the IBRA planning group, while version 3.2 was circulated widely for comment and discussion. Versions 3.3 and 3.4 were retained within the working groups; version 3.5 was prepared for the technical meeting at Alice Springs in July 1994, with final approval in March 1995. IBRA4.0 is the result of that meeting, being thoroughly reworked in both text and the associated map (Figure 1.13). IBRA4.0 became the first version made available for widespread reference and use within governmental and scientific communities.

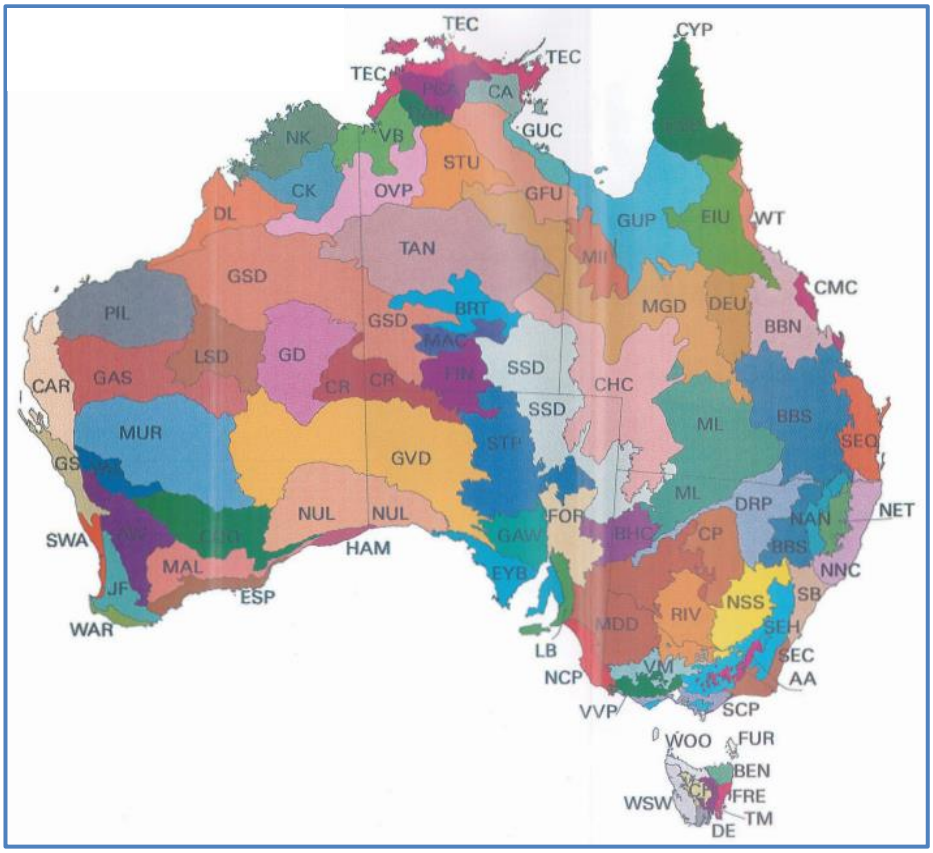

Figure 1.13: IBRA4.0 outlining all 80 bioregions of Australia. **Source:** Thackway and Cresswell (1995). For region codes, see Thackway and Cresswell (1995, p. 34).

[16] Follows: Thackway and Cresswell (1995).

Bioregions are not bounded by state or territory borders, that is, straight lines on a map. IBRA bioregions are delineated by landforms, climate variables, flora distribution, all free flowing and unrestricted. Hence, many bioregions are shared between jurisdictions, though some are restricted within jurisdictions (Table 1.3).

Table 1.3: IBRA4.0 – number of regions restricted and shared between jurisdictions. **Source:** Thackway and Cresswell (1995, p. 42). Jurisdictions are listed in a clockwise fashion from Queensland.

Jurisdiction	Restricted	Shared	Total
Queensland	7	13	20
New South Wales	4	13	17
Australian Capital Territory	0	2	2
Victoria	3	8	11
Tasmania	7	1	8
South Australia	4	11	15
Western Australia	18	8	26
Northern Territory	7	13	20
Australia	**50**	**69**	**119**

Thirty bioregions are shared between jurisdictions, therefore these (30) bioregions occur two or more times giving a total of sixty-nine bioregions that are shared between States and Territories, while 50 bioregions are restricted to just one jurisdiction.

Updating IBRA

As better information from state and territory agencies becomes accessible (e.g. vegetation communities, ecosystems, spatial mapping), IBRA was enhanced and updated. During the period 1998-2000 a major review of bioregional boundaries was undertaken which resulted in IBRA5.1 (2000). The current IBRA is version 7, an update of IBRA6.1 (2005), the newer version defining 89 bioregions and 419 subregions compared to 85 bioregions and 403 subregions ascribed in IBRA6.1. The naming and coding of IBRA bioregions and subregions (in IBRA6.1) was also reviewed and updated to a more consistent format and standard (Department of Environment and Energy 2016).

IBRA7 [17] *(2012)*

IBRA7 now includes four new oceanic bioregions: Coral Sea Bioregion, Subantarctic Islands Bioregion, Pacific Subtropical Islands Bioregion and Indian Tropical Islands

[17] Format of term "IBRA7" follows that used by Department of Environment and Energy (2016).

Bioregion. These bioregions account for Australia's island territories including Lord Howe Island in the Pacific Ocean and the Coral Sea Islands Territory, Macquarie Island in the Southern Ocean and Christmas Island in the Indian Ocean. IBRA7 also includes six new subregions in South Australia and seven new subregions in the oceanic bioregions (Department of Environment and Energy 2016).

Realigned boundaries that more accurately reflect bioregions and subregions, particularly those that cross state borders (Figure 1.14) have now been updated in IBRA7. Many coding inconsistencies and boundary matching for Victoria and Tasmania and the Northern Territory and Western Australia have been eliminated. The bioregional and associated sub-regional boundaries in the Australian Capital Territory, Queensland, New South Wales and South Australia have been more accurately refined to reflect improved spatial information in these regions (Department of Environment and Energy 2016). All changes were jointly defined and agreed by Commonwealth, State and Territory nature conservation agencies. Also, the IBRA dataset is now more closely aligned to Geoscience Australia 1:100K State borders (Research Data Australia (ANDS) 2017).

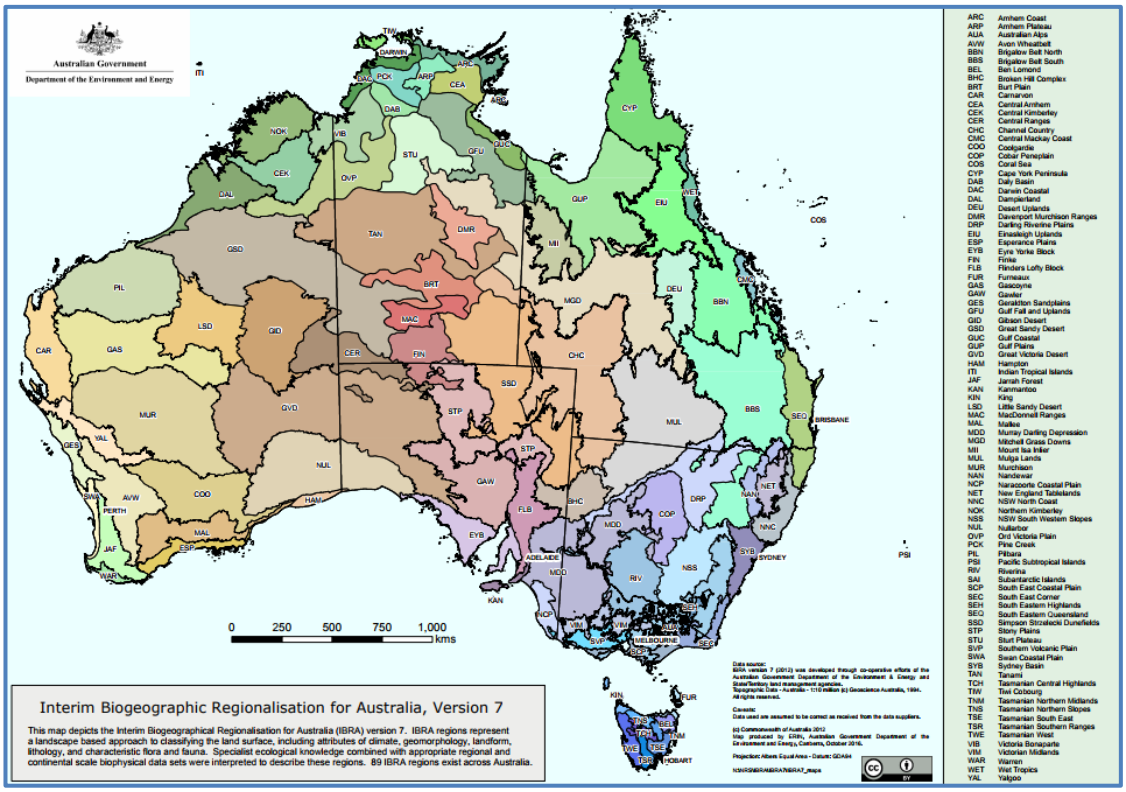

Figure 1.14: IBRA7 (2012) bioregions, which now include Coral Sea (COS), Pacific Subtropical Islands (PSI), Subantarctic Islands (SAI) and Indian Tropical Islands (ITI). **Source:** Department of Environment and Energy (2016).

In the past, there have been some questions raised on the ecological basis of biogeographic regions, "however, the IBRA is now firmly established as a conservation-planning tool at both national and regional levels and its further refinement and application will continue to be important components of the conservation effort" (my emphasis) (Peters & Thackway 1998, p. 36).

1.7.2 The Tasmanian context

Up to and including IBRA4.0 (1995)

Tasmania's contribution for modifying the existing State regionalisation up to and including IBRA4.0, was a combination of two 1:500,000 scale nature conservation maps, one used by the Tasmanian Herbarium, the other, nature conservation regions, that adopted by the then Tasmanian Forestry Commission (Orchard 1988) (Figures 1.15 and 1.16, see following page).

The regions within the two maps were aggregated to that with similar climate, landform, geology/lithology, vegetation and floristics (Thackway & Cresswell 1995) to form eight Tasmanian IBRA bioregions identified by the Tasmanian Parks and Wildlife Service in 1994 (Peters & Thackway 1998).

During preliminary discussions, commonalities were observed between Tasmania's north east portion and Victoria's Coastal Plain region. It was resolved that Victoria's region should not be grouped with Tasmania's nature conservation regions 2, 5 and 6, however, it was agreed that Victoria's Wilsons Promontory region should be combined with Tasmania's Furneaux Region (2) on the basis of similarity of geomorphology, geology, climate and vegetation; this IBRA bioregion named Furneaux (Thackway & Cresswell 1995).

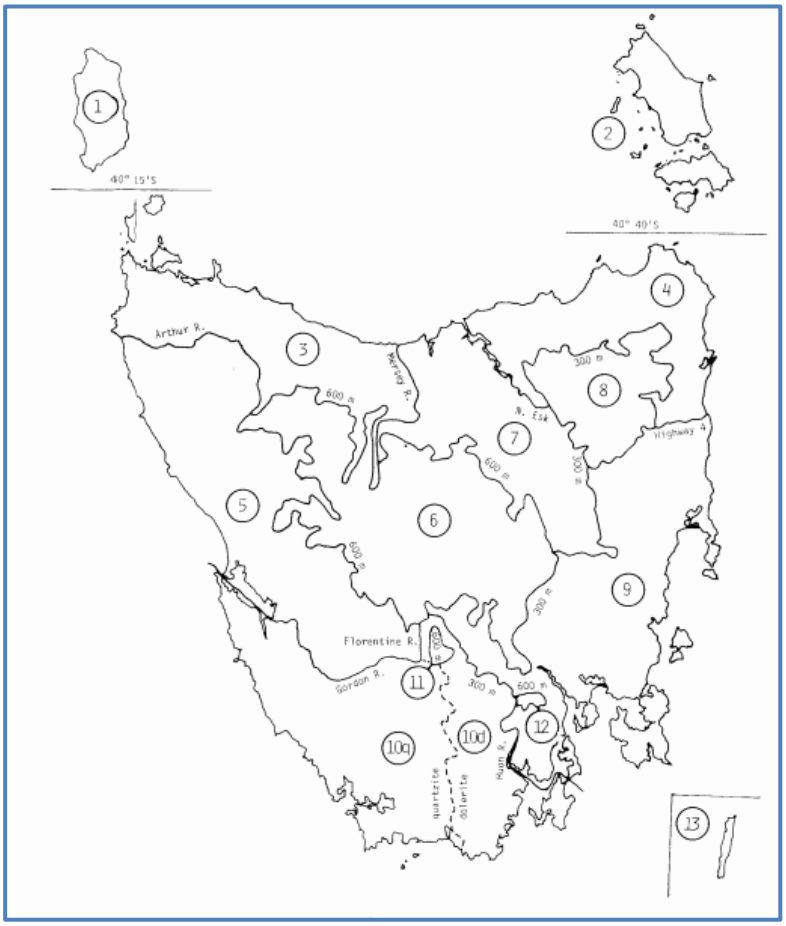

Figure 1.15: Tasmanian Herbarium Regions:
1 – King Island
2 – Furneaux
3 – North West
4 – North East
5 – West Coast
6 – Central Highlands
7 – Midlands
8 – Ben Lomond
9 – East Coast
10q – South West (quartzite)
10d – South West (dolerite)
11 – Mt Field
12 – Mt Wellington
13 – Macquarie Island
Source: Orchard (1988).

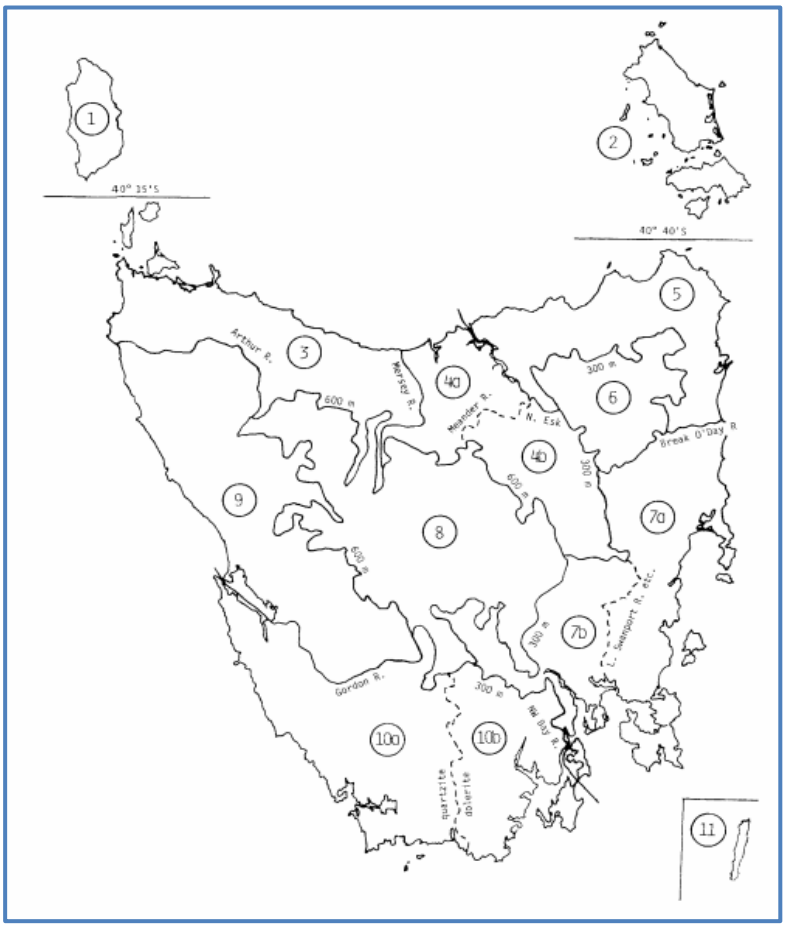

Figure 1.16: Nature Conservation Regions adopted by the Tasmanian Forestry Commission:
1 – King Island
2 – Furneaux Group
3 – North west
4a – North Coast and Hills
4b – North Midlands
5 – North East Lowlands
6 – North East Highlands
7a – East Coast and Tiers
7b – East Southern Midlands
8 – Centre
9 – West
10a – South quartzite
10b – South dolerite
11 – Macquarie Island
Source: Orchard (1988).

IBRA5.0 and 5.1 [18]

Enhanced methods in modelling of species and assemblages, along with new comprehensive biological data, provided an opportunity to refine Tasmania's IBRA regions. Improved environmental data was now resampled at 1km squares. Biological datasets that were considered most useful included scientific publications, government databases and personal collections, these based on extent of coverage and representative of a species range. From a series of models – naïve and expert – species range simulations were generated for a series of fauna species (birds, mammals, frogs and reptiles) and trees. Assemblage models were produced correlating joint displays of pairs, for example, forest birds and trees. A global assemblage model incorporating all individual models was then used as a basis for interpreting possible biogeographical boundaries (Figures 1.17 and 1.18).

Tasmanian IBRA4.0 (1995) was driven by collating regions based on native flora with no account taken of faunal evidence. However, Tasmanian IBRA5.0 better reflects the ranges of reptiles, frogs and mammals in addition to that of forest birds and has been accepted by those zoologists who have viewed the newer version.

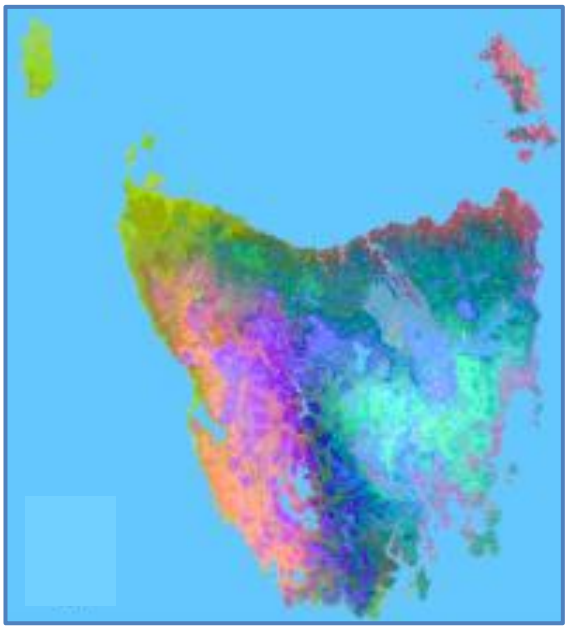

Figure 1.17: A global visualisation model of trees, forest birds, frogs, mammals and reptiles used in detailing proposed bioregions for IBRA5.0. **Source:** Peters and Thackway (1998).

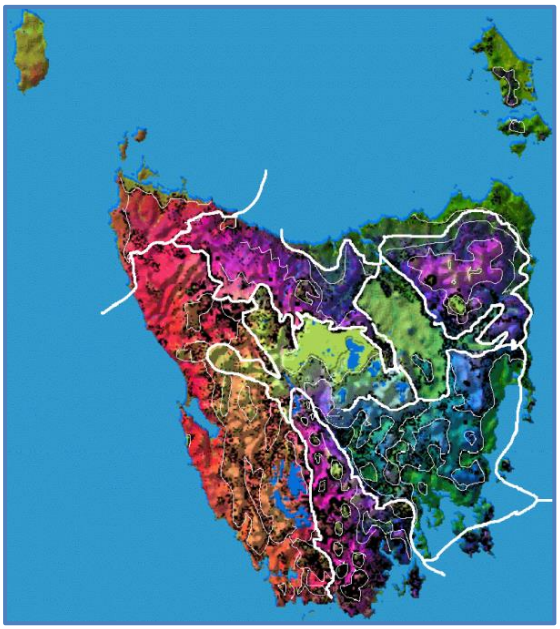

Figure 1.18: A draft of possible new boundaries from a workshop detailing proposed bioregions for Tasmania IBRA5.0. **Source:** Peters and Thackway (1998).

[18] Follows: Peters and Thackway (1998).

Major alterations occurred between IBRA4.0 and 5.1 in nearly all Tasmanian IBRA regions (Table 1.4). Here, note that version 5.1 is a national approved version of draft 5.0, this being a workshop version of revised IBRA boundaries developed by individual jurisdictions (Environment Australia 2000). The new proposed Tasmanian IBRA (version 5.1) map was also presented (Figure 1.19).

Table 1.4: Changes to Tasmanian IBRA bioregions between versions 4.0 and 5.1. **Source:** Environment Australia (2000).

Bioregion (IBRA4.0)	Changes (IBRA5.1)
Ben Lomond	North east coastal areas split off and joined to Flinders Island, named Flinders (IBRA region).
D'Entrecastreaux	Renamed Southern Ranges and extended northwards into Central Highlands region.
Freycinet	Renamed South East, extended southwards to join Southern Ranges and extended westward.
Tasmanian Midlands	Reduced significantly, renamed Northern Midlands.
West and South West	Northern boundary moved southwards and renamed West.
Woolnorth	Split into two regions – King, which includes King Island and North western portion of Tasmania, and Northern Slopes.

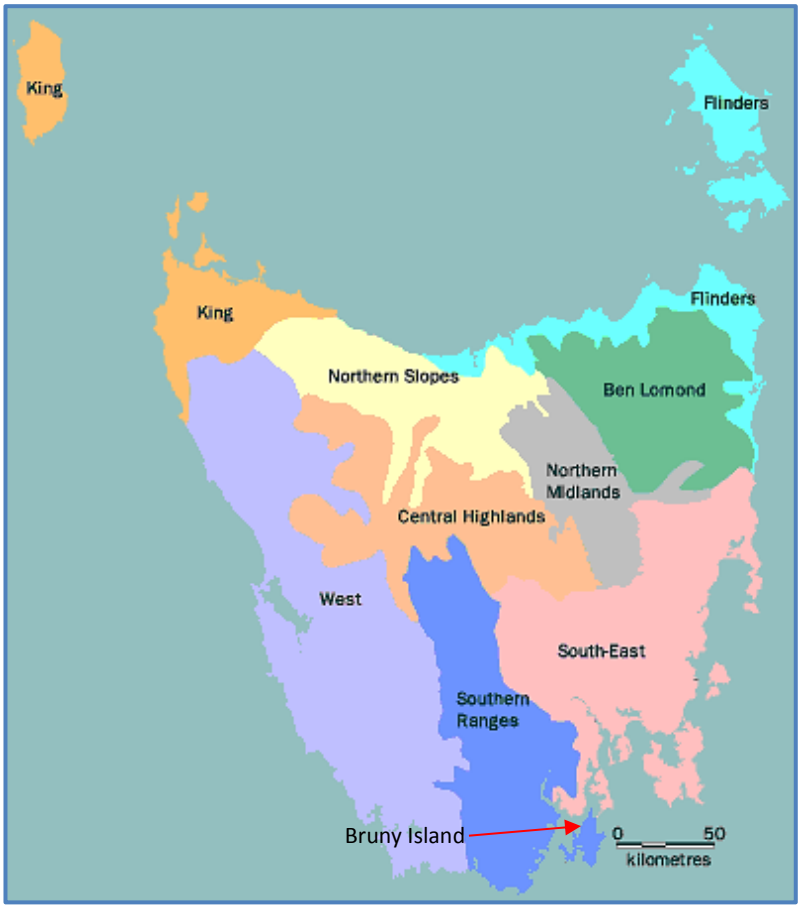

Figure 1.19: Tasmanian **IBRA5.1** bioregions. **Source:** Resource Planning and Development Commission (2003).

Note: the split of Bruny Island (identified on map) to two bioregions; North Bruny forms part of South East bioregion, while South Bruny is integrated in Southern Ranges bioregion. This is a carryover of the Tasmanian Herbarium Regions and Nature Conservation Regions maps (Orchard 1988) delineation. This arrangement is supported by contemporary field observations where the floristics and botanical structure are meaningfully different between North and South Bruny.

Tasmania's IBRA5.1 coastal regional descriptions of Flinders, South-East, Southern Ranges, West, King and Northern Slopes (as interest is in these regions only) are provided in Appendix 1A.1.

IBRA6.1/6.2

The only recorded changes from IBRA5.1 to 6.0/6.2 in the Tasmanian context, is the renaming of the Flinders bioregion to Furneaux and designating the Tasmanian portion of this region as a subregion (of Furneaux) named Flinders (Figure 1.20), with the Victorian portion of the Furneaux region now named Wilson Promontory.

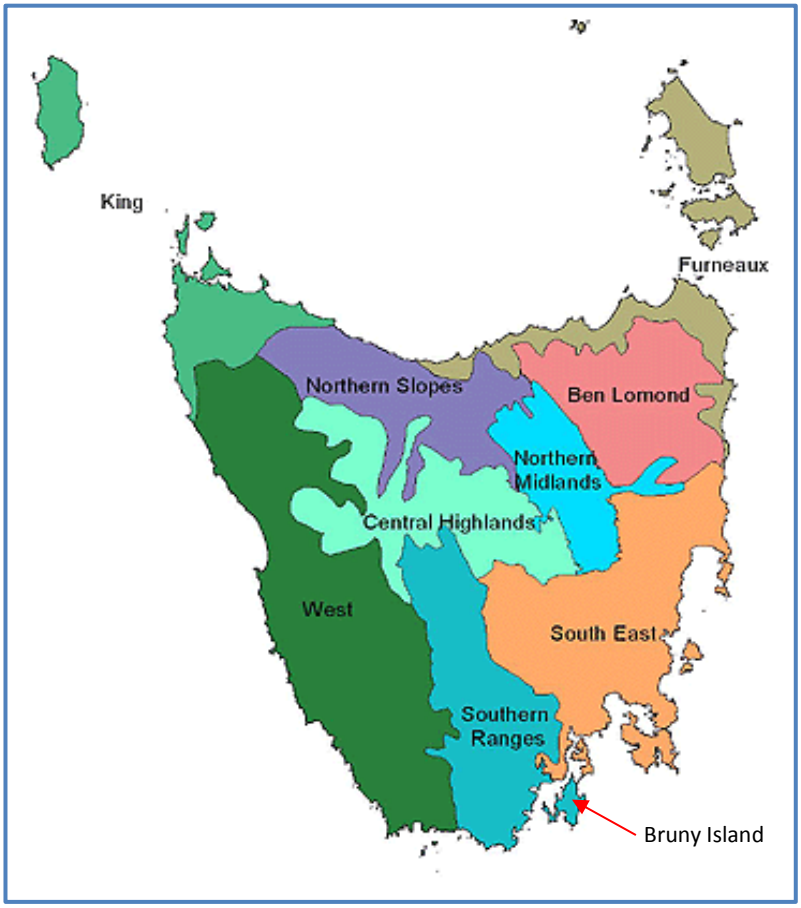

Figure 1.20: Tasmanian **IBRA6.2** bioregions. **Source:** DPIPWE (2016). **Note:** the Furneaux bioregion extends to Wilson Promontory in Victoria.

Note: the split of Bruny Island (identified on map) to two bioregions is still evident.

IBRA7

The only change that occurred within a Tasmanian context from IBRA6.1/6.2 to IBRA7 was the removal of South Bruny (island) from Southern Ranges (TSR) and including it in South East (TSE) (Figure 1.21). This resulted in Bruny Island (north and south) being regarded as a single unit belonging to one bioregion rather than the island belonging to two bioregions (as in IBRA6.1). However, this was an unintended consequence as there was no plan on Tasmania's part to alter the delineation of Bruny

Island from its current state of being split to two bioregions. The revocation of the change to Bruny Island (returning it to the status of that recorded in IBRA6.1) will be reflected in a new version of IBRA (Faulkner 2018).

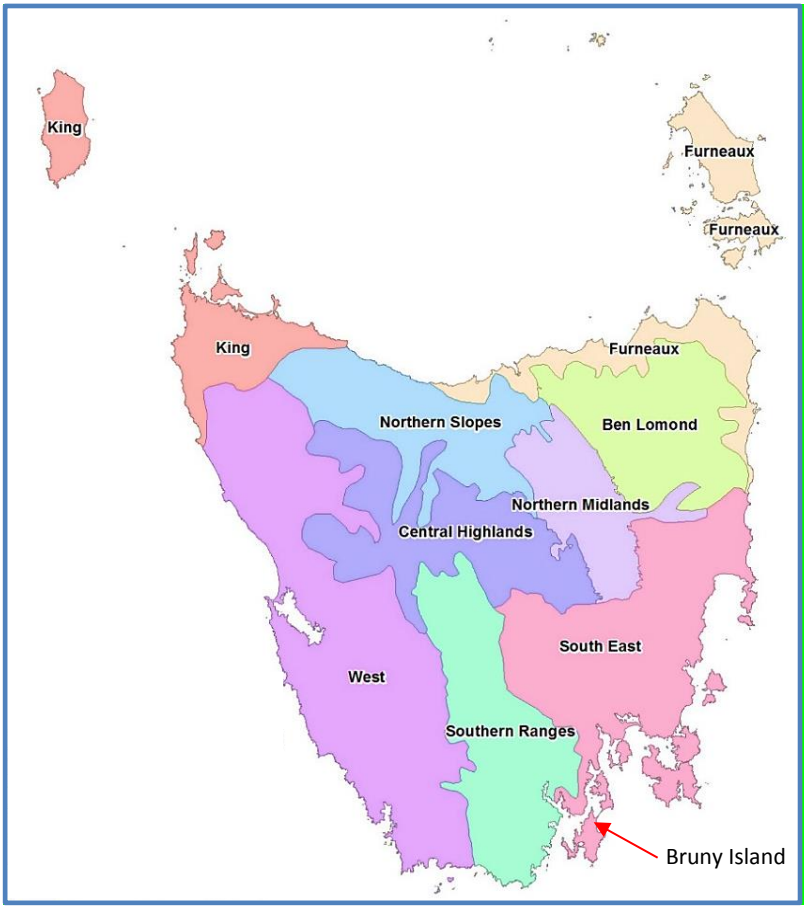

Figure 1.21: Tasmanian **IBRA7** bioregions.

Source: courtesy V Prahalad.

Note 1: the Furneaux bioregion extends to Wilson Promontory in Victoria.

Note 2: the split of Bruny Island has been removed and the whole island has been incorporated into the South East bioregion.

Note: for the remainder of this study/report, reference to IBRA will be in the context of version 6.1, as this version accurately accounts for the intended delineation of IBRA boundaries in Tasmania's jurisdiction (Faulkner 2018). Therefore, all study site selections and reporting will follow IBRA6.1.

1.8 IMCRA

1.8.1 National IMCRA Regions

Background [19]

In the mid-1980s a nationwide marine regionalisation for Australia was ratified by the (Australian) Council of Nature Conservation Ministers. This agreement delineated at a provincial (broad) scale, the major marine and coastal regions of the Australian continent. In 1986, this regionalisation was modified and presented as a proposal for a national representative system for protected areas within the coastal zone. However, the proposal was too generalised, broad-scale and lacking in adequate detail to be useful in bioregional conservation efforts.

In the meantime, several States had developed coastal and inshore (including estuarine) regional classifications using multivariate methods on ecosystem diversity (e.g. see Edgar *et al.* (1995)). During the early- to mid-1990s, the Commonwealth Government provided support for the development of a single ecosystem-level regionalisation based on these earlier classifications, this became known as the "Interim Marine and Coastal Regionalisation of Australia". The regionalisation was nested in two parts: a) meso scale – inshore waters up to the 200-metre isobath (originally the 3-nautical mile limit, the limit of State jurisdictions), and b) provincial scale – larger scale regions that extend to the 200-nautical mile limit, generally known as the Exclusive Economic Zone (EEZ). Following several technical meetings and reviews, IMCRA3.3 was endorsed and released for governmental and public use "to provide a regional framework for planning sustainable resource development and biodiversity conservation" (my emphasis) (p. 15).

Nominal attributes for IMCRA [20]

To assist in the delineation of IMCRA boundaries, two major attributes, each with supplementary features, were adopted: biological – made up from sponges, fishes, corals, and sea grasses; and physical – made up from bathymetry, coastal geomorphology, sediments, currents, water chemistry, and water temperature.

[19] Follows: Interim Marine and Coastal Regionalisation for Australia Technical Group (1998) (IMCRATG).
[20] Follows: IMCRATG (1998).

For the meso-scale regionalisation of IMCRA, each State and the Northern Territory provided biological and physical data, inshore fish data, data from published literature and digital maps. Several jurisdictions already had defined coastal/marine regions, and these became the preliminary basis of the original IMCRA regions.

Development of IMCRA to version 3.3 [14]

A condensed account of the timeline and development of IMCRA is presented in Table 1.5 and a map displaying meso-scale bioregions is provided in Figure 1.22 (page 1.30).

Table 1.5: Condensed version of timeline and stages in the development and approval of IMCRA. **Source:** IMCRATG (1988).

Date	Action
Mid 1980s	Nationwide marine regionalisation for Australia was ratified by the (Australian) Council of Nature Conservation Ministers, this too generalised to be useful.
Mid 1980s to early 1990s	States and Northern Territory develop separate near-shore and coastal regional classifications for individual jurisdictions.
Jan 1995	IMCRA 1.0 detailing approach for developing IMCRA circulated for comment: *A proposal to develop an Interim Marine-Coastal Regionalisation of Australia (IMCRA)*.
Mar 1995	Agreement reached by State and Northern Territory marine management and research agencies on an approach in developing the meso-scale IMCRA regionalisation. IMCRA 1.0 presented comprising 56 inshore regions.
Nov 1995	GIS dataset developed and descriptions for each meso-scale region compiled. IMCRA 1.1 distributed for comment: *An Interim Marine and Coastal Regionalisation for Australia (IMCRA), Stage 1 – the nearshore component: a framework for establishing the national system of marine protected areas.*
Dec 1995	IMCRA 1.1 accepted and recommendations made for preparing version 2.0. State, Northern Territory and Commonwealth agencies agree to develop a single regionalisation for the EEZ that would be known as IMCRA.
Apr 1996	Marine Protected Area Program workshop in Adelaide accepts the meso-scale IMCRA as the bioregional planning framework for developing a National Representative System of Marine Protected Areas.
Sep 1996	IMCRA 2.0 distributed for comment: *Interim Marine and Coastal Regionalisation for Australia: an ecosystem-based hierarchical classification of coastal and marine environments, Stage I – The inshore waters.*
Nov 1996	IMCRA 2.0 approved and recommendations made for preparing version 3.0 to include Commonwealth waters and External Territories. Inshore and offshore waters working groups agree on a proposal to integrate their regionalisation efforts.
Mar 1997	Tables and maps for version 3.0 distributed to State, Northern Territory and Commonwealth agencies for comment.
Dec 1997 to Feb 1998	Public consultation period – comments then included in version 3.3.
Jun 1998	Endorsement of IMCRA by Australian and New Zealand Environment and Conservation Council (ANZECC).

The principle outcome of IMCRA3.3 is the inshore regionalisation of Australia coastal waters to 60 (from 56) meso-scale regions which extend from the coast to the edge of the continental shelf, this defined as the 200 metre isobath (Figure 1.22) (Commonwealth of Australia 2006).

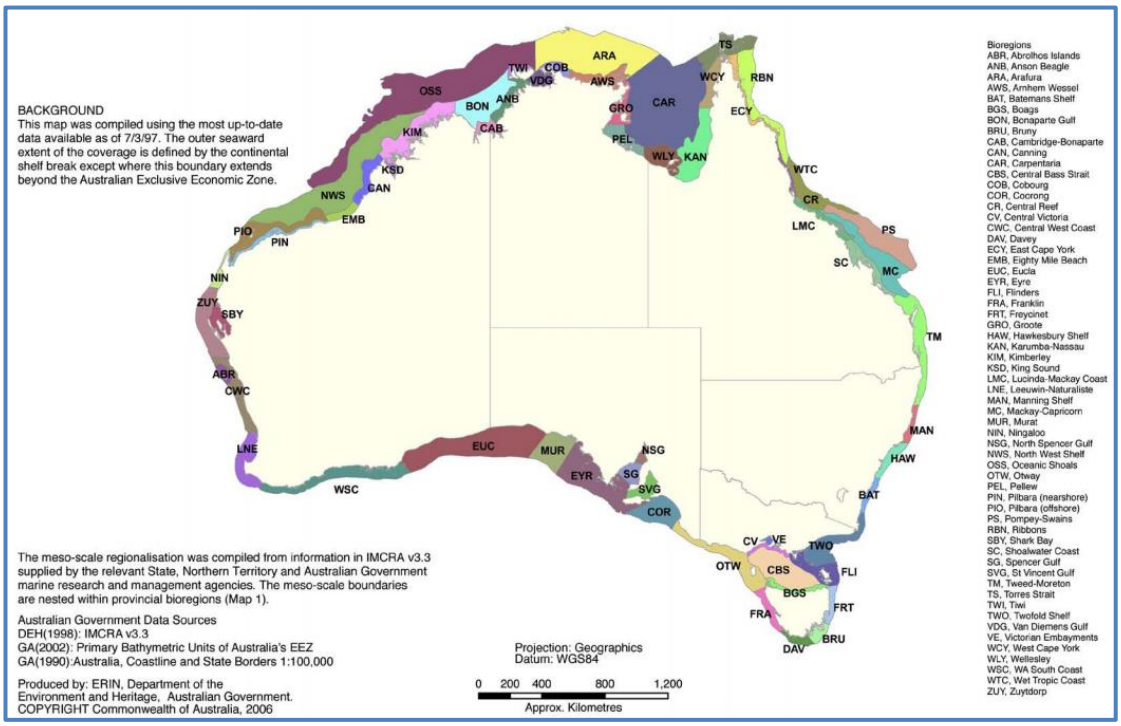

Figure 1.22: IMCRA version 3.3 meso-scale bioregions. **Source:** Commonwealth of Australia (2006).

IMCRA v4.0 [21]

The Integrated Marine and Coastal Regionalisation of Australia v4.0 (IMCRA v4.0) is the result of the combination of the Interim Marine and Coastal Regionalisation of Australia (IMCRA version 3.3), (meso-scale regionalisation of inshore waters), with the National Marine Bioregionalisation (NMB) (the regionalisation of off-shelf waters). In combining these two national marine regionalisations, IMCRA v4.0 covers Australia's waters from the inshore coast to the edge of Australia's Exclusive Economic Zone excluding Antarctica and Heard and Macdonald Islands (Figure 1.23) (Commonwealth of Australia 2006).

[21] Format of term "IMCRA v4.0" follows that used by Commonwealth of Australia (2006).

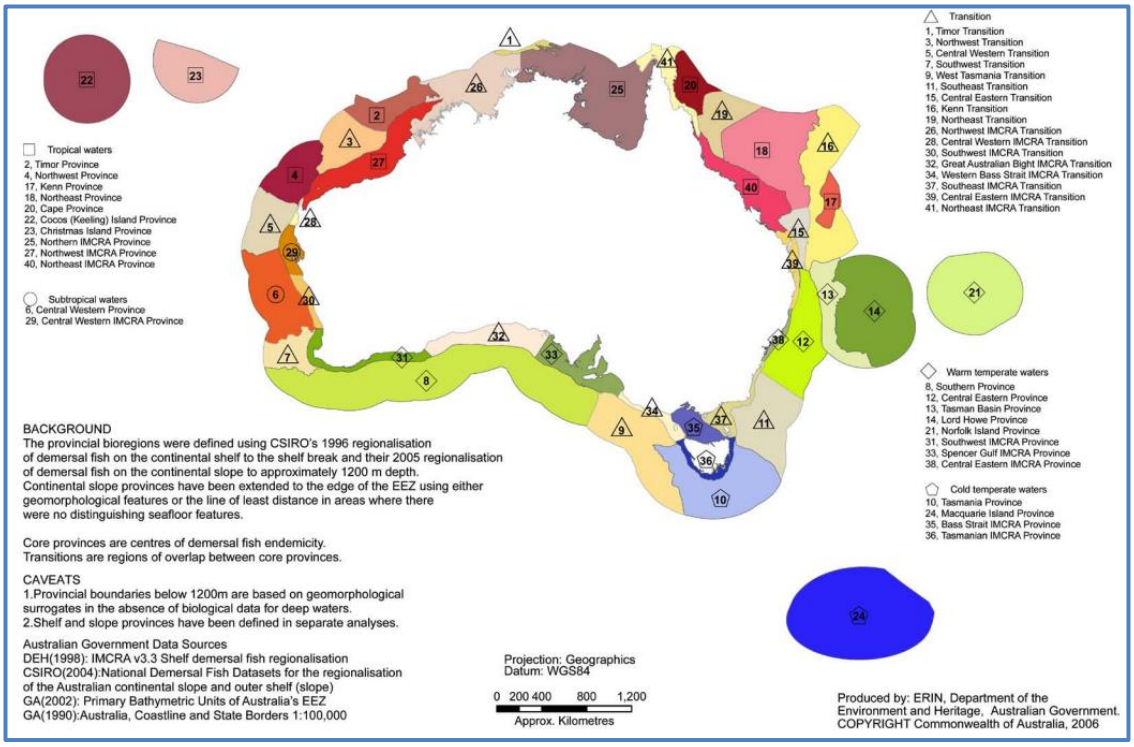

Figure 1.23: IMCRA version 4.0 provincial regions, a combination of IMCRA meso-scale bioregions.
Source: Commonwealth of Australia (2006).

1.8.2 The Tasmanian context

An integrated management of Tasmanian marine ecosystems was considered during the 1970s[22] [23]. At this time several issues highlighted severe degradation of coastal marine areas, predominantly those localised in some regions of the State. Identified problems included contamination of estuarine shellfish and fish (Dix *et al.* 1975) and declining fish catch despite an increasing effort (Harrison 1975). Governmental efforts were applied to remedy these issues, such as controlling sewage discharge and the disposal of mineral processing waste at sea. At the same time, two agencies, National Parks and Wildlife Service and the Tasmanian Fisheries Development Authority, recognised the need for a system of representative marine reserves to protect coastal marine species for conservation (Kriwoken & Haward 1991). Marine biota surveys were progressed around the State's coastline during the early 1980s to determine the number of biotic regions and to further identify locations for a representative marine reserve in each of the determined bioregions. Three marine provincial bioregions were identified and recommendations for marine reserves tabled. However, due to the lack of political will,

[22] Follows: Edgar *et al.* (1995).
[23] Follows: Commonwealth of Australia (2006).

these recommendations were delayed and not progressed until 1989 (Kriwoken & Haward 1991), when finally, in 1991, four reserves were declared, though smaller in size.

Funding provided by the Commonwealth Government under the Ocean Rescue 2000 project, permitted extensive biological surveys to be carried out during the early 1990s to provide baseline data of marine animals and plants, to measure the impact of established marine reserves on reef biota and to refine the regionalisation of Tasmania's coastal ecosystems. Following survey work, the State's coastal marine habitats were regionalised by multivariate analysis of various physical and biological data, then identified regional boundaries were compared to define consistent patterns. Data used in this study included the following attributes: biological – reef biota (reef plants and animals), beached washed shells, and beach seined fishes; and physical – sea surface temperatures (February 1989-92 and July 1989-92), and bathymetry.

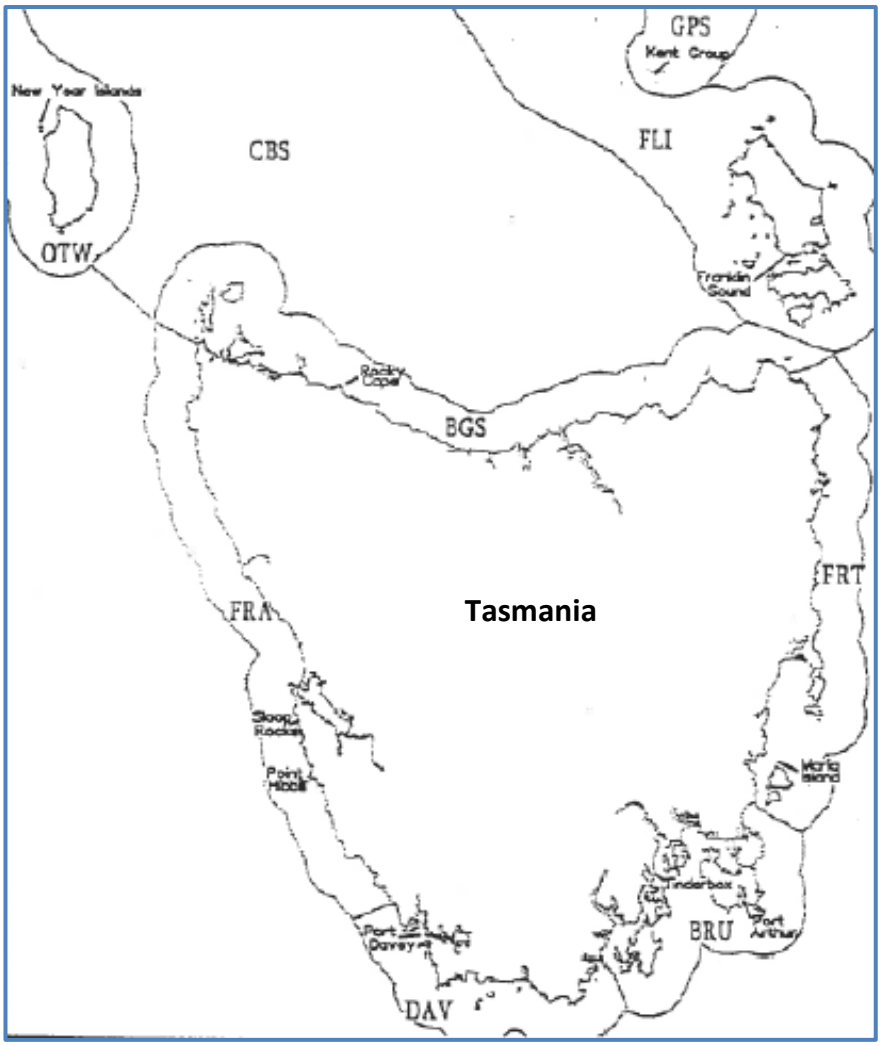

Figure 1.24: Bioregions inferred from reef habitats around Tasmanian coast. Bioregions abbreviated as follows:
GPS – Gippsland
FLI – Flinders
FRT – Freycinet
BRU – Bruny
DAV – Davey
FRA – Franklin
OTW – Otway
BGS – Boags
CBS – Central Bass Strait (NB: this region (CBS) is lacking in reef systems; is offshore from all Tasmanian landmass and islands).
Source: Edgar *et al.* (1995, p. 41).

Subsequent analysis of the datasets, two biogeographical provinces (bioprovinces) were determined: a) Bassian, and b) Tasmanian bioprovinces, this due to the differences in the number of species that abundantly occur in each bioprovince as rare or absent in the other found between Bass Strait habitats and those to the south. Based on the distribution of reef animals and plants, each of the bioprovinces could now be subdivided into four distinct biogeographic regions (bioregions) (Figure 1.24, previous page): The Bassian bioprovince comprises Gippsland, Flinders, Otway, and Boags bioregions, while the Tasmanian bioprovince is made up of Freycinet, Bruny, Davey, and Franklin bioregions.

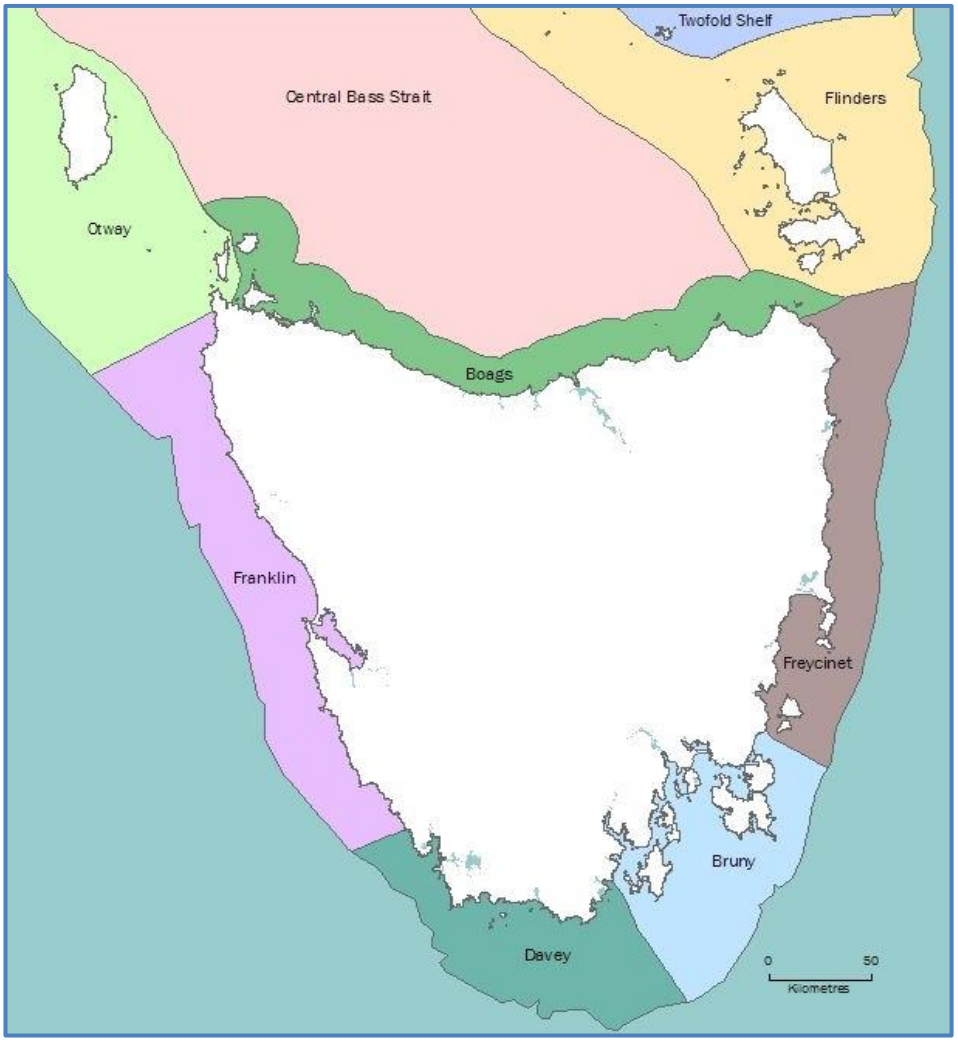

Figure 1.25: IMCRA version 3.3 Tasmanian meso-scale coastal bioregions. **Source:** Tasmanian Planning Commission (2009).

Bioregion names and codes:
Flinders = **FLI**
Freycinet = **FRE**
Bruny = **BRU**
Davey = **DAV**
Franklin = **FRA**
Otway = **OTW**
Boags = **BGS**
Central Bass Strait = **CBS**
Twofold Shelf = **TWO**

IMCRA version 3.3/v4.0

Work by Edgar *et al.* (1995) (see above) was submitted to Australian Nature Conservation Authority (ANCA) by the Tasmanian Parks and Wildlife Service (TPWS) as Tasmania's contribution to an interim bioregionalisation of Australia's maritime

coast. Once converted to a digital format and added to the national coverage, ANCA checked the output against hard copies provided by TPWS (IMCRATG 1998). This provided adequate information and coverage of Tasmania's coastal bioregions to be included in the development of IMCRA to version 3.3 (Figure 1.25, previous page). The only variation to the original proposal was the renaming of Gippsland (GPS) to Twofold Shelf (TWO). A description of each Tasmanian IMCRA bioregion is presented in Appendix 1A.2. Region CBS is not included as it has no connection to any portion of Tasmania's coastline.

Subsequently, IMCRA version 3.3 has been aggregated with NMB (regionalisation of off-shelf waters) to form IMCRA v4.0. Tasmania's position within this version's provincial bioregions is presented in Figure 1.26.

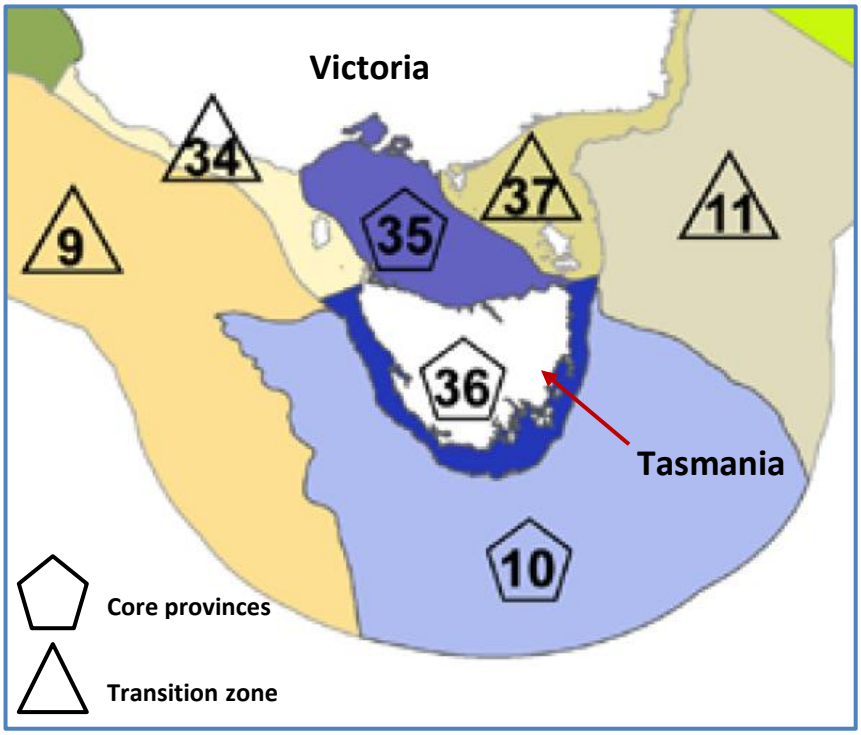

Figure 1.26: Tasmania's position within **IMCRA v4.0** provincial bioregions. **Source:** Commonwealth of Australia (2006).

Core provinces (demoted by pentagon) are centres of demersal fish endemicity:
10 = Tasmania province
35 = Bass Strait (IMCRA) province
36 = Tasmanian (IMCRA) province

Transitions (denoted by triangle) are regions of overlap between core provinces:
9 = West Tasmanian transition
11 = Southeast transition
34 = West Bass Strait IMCRA transition
37 = Southeast IMCRA transition

1.9 Key research questions and study aims

The above discussion highlights that there is no one size fits all category for regionalisation of Tasmanian coastal saltmarshes. Land weather forecast districts are terrestrial based with boundaries determined by past climate, coastal weather forecast districts are bounded by geomorphological features delineated by a human interest, estuarine classification has been determined by physical characteristics such as size of

catchment and length of estuary, geographical regions determined subjectively again with a human bias, IBRA is terrestrial and has attributes of vegetation and climate, IMCRA version 3.3 is generally coastal marine based, while IMCRA v4.0 includes inshore and offshore areas. It has become apparent that possibly the best option of regionalisation of coastal saltmarshes could either follow an IBRA or IMCRA regionalisation, BOM coastal districts, geographical or an estuarine classification, as it is acknowledged that saltmarshes are neither truly terrestrial nor truly marine.

Questions

A key question was identified:

- Is the pattern of natural variation of the Tasmanian coastal saltmarsh habitat (e.g. vegetation, soils) described here in this thesis, most aligned to pre-existing biophysical regionalisations (e.g. IBRA, IMCRA), weather forecast districts, geographic regionalisation, or an estuarine classification?

Study aims

The overall aim of the project was to understand why plant species are located in terms of soil and climate variables, account for carbon stores in coastal marshes and investigate plant species resilience to climate change. Identified aims were as follows:

- Provide a natural classification of Tasmanian coastal saltmarsh vegetation at a fine scale;
- Develop a vegetation community key useful for field-based ecological studies of coastal saltmarshes;
- Ascertain if a form of natural regionalisation can determine saltmarsh type by vegetation community composition;
- Identify plant species correlation to soil types, edaphic factors and climatic conditions;
- Study the carbon content of coastal saltmarshes soils and identify the value of carbon storage in Tasmanian coastal saltmarshes; and
- Investigate the tolerance of saltmarsh plant species to environmental and climate changes.

An account of relevant past and current research in coastal saltmarsh vegetation and soils and their inter-relationships in a global/Australian/Tasmanian context follows.

1.10 Saltmarsh research

1.10.1 International

The saltmarsh ecosystem has held a long standing interest for authors such as Ranwell (1972), Chapman (1974), Long and Mason (1983), Adam (1990), Saintilan (2009a) and others. However, in many cases, attention has been limited to the distribution and patterns of vegetation variance (Adam 2002), such as Partridge and Wilson (1988), Thannheiser and Holland (1994), and Kunza and Pennings (2008). In recent years, with an increasing focus on either conservation or restoration, a renewed and expanding interest in saltmarshes has evolved especially in Europe and North America (Desender *et al.* 1998; Desender & Maelfait 1999; Irmler *et al.* 2002; Finch *et al.* 2007; Pétillon *et al.* 2008). This has led to emerging studies into saltmarsh soils, such as Snow and Vince (1984), Álvarez-Rogel *et al.* (2000), Molina *et al.* (2003), Landi and Angiolini (2015), and some invertebrate taxa, for example, Valiela *et al.* (2004), Finch *et al.* (2007), Dhuyvetter *et al.* (2007), McCall and Pennings (2012). Recently, a latitudinal study on a 2,000km gradient on Chile's west coast, found that variations of saltmarsh plant zonation are explained by climatic, tidal and edaphic factors (Fariña *et al.* 2018), thus suggesting that these attributes may be very important in defining regionalisation of coastal saltmarshes.

1.10.2 Australia

A similar renewal in interest has been somewhat lacking in Australia until recently. During the 1990s, Fairweather (1990) noted that Australian saltmarshes had received the least attention of all marine habitats and their ecological values were being ignored. Furthermore, Laegdsgaard (2006) noted that there has been little study of the terrestrial fauna of saltmarshes leading to assumptions that Australian saltmarsh fauna is similar to those found in other locations around the world (Morrisey 2000). Indeed, Boon (2011) maintained that: "Australian saltmarshes suffer from massive knowledge gaps (e.g. habitat and food for saltmarsh fauna, including invertebrates), and that until recently (2009), the most recent text with substantive sections on Australian coastal saltmarsh was 20 years old" (Boon 2011, p. 131). Nevertheless, during the last decade the growing

appreciation of saltmarsh values and a realisation that predicted climate change related sea-level rise will impact saltmarshes, have led to increased research into this challenging environment (Kelleway *et al.* 2009; Saintilan & Adam 2009; Saintilan & Rogers 2013; Saintilan *et al.* 2018).

For Australia, in an important development during August 2013, the Australian Federal Minister for the Environment amended the list of threatened ecological communities under Section s266B of the *Environment Protection and Biodiversity Act 1999* (EPBC Act) by including the Subtropical and Temperate Coastal Saltmarsh Community in the "vulnerable" category (Department of the Environment and Energy 2013). Previously, NSW was the only Australian jurisdiction to list coastal saltmarsh as endangered, while other jurisdictions, including Tasmania, do not list this ecological community (Department of the Environment and Energy 2013).

Australian coastal saltmarsh regionalisation

To enhance awareness and develop an improved comprehension of conservation and intrinsic values, Bucher and Saenger (1989) compiled an inventory of estuaries and enclosed marine waters of the Australian coastline. The authors used various geomorphic characteristics (e.g. total area/area of mangrove, seagrass, saltmarsh, catchment size and clearance, water quality), and climatic variables (e.g. rainfall, supply of fresh water), to provide a map of Australia's coastal biogeographic (zones based on the scheme adopted by the Australian Council of Nature Conservation Ministers in 1986) and climate zones (Figure 1.27).

At an initial pass, the inventory data and map provide a reasonable interpretation of the position in the landscape and attributable climate variations of Australia's estuaries. However, the authors caveat that many Australian estuaries are poorly known and that there is an undoubted wealth of information that was untapped by their study. The authors conclude that more research is required on catchment characteristics, water quality and conservation values, and that detailed mapping is essential (Bucher & Saenger 1989, p. 380).

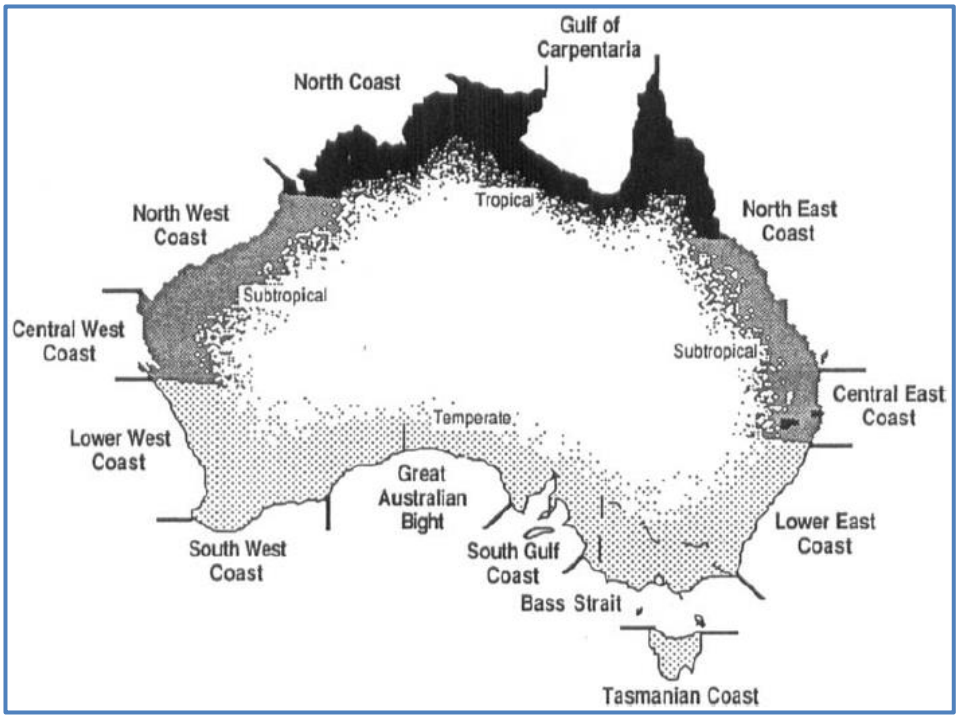

Figure 1.27: Australian coastal biogeographic and climate zones. **Source:** Bucher and Saenger (1989).

In other examples at a national scale, work has been carried out on identifying biogeographic patterns in saltmarsh systems, for example, Bridgewater and Cresswell (2003) and Saintilan (2009c), both based on the Australia's Virtual Herbarium (available at: http://avh.chah.org.au/) (AVH).

Bridgewater and Cresswell (2003) applied a new approach of combining IBRA and records from AVH to determine five main phytogeographic groups for saltmarshes, each group further divisible into sub-groups. Using data from AVH (which, at the time was a novel version) and information from personal knowledge, previously published papers and reports, the authors identified halophytic plant species distribution on a nationwide basis. This was based on species occurrence in individual bioregions, which included those found in inland Australia as saltpans and lakes (Figure 1.28). Three groups: a) *Halosarcia doleiformis-Halosarcia leptoclada* Group, b) *Sclerostegia tenuis* Group, and c) *Halosarcia pergranulata* Group – are found inland and central coastal Western Australia, central arid and semi-arid regions, and in the Murray-Darling Basin. Another group – *Suaeda arbusculoides-Halosarcia indica julacea* Group – is found on the northern and central Australian coastline; the final group – *Sclerostegia* (now *Tecticornia) arbuscula-Juncus kraussii* Group – is found on Australia's southern coastline (excluding the Great Australian Bight region) and Tasmania (Figure 1.29). This group is further divided into four sub-groups and reviewed in Chapter 3.

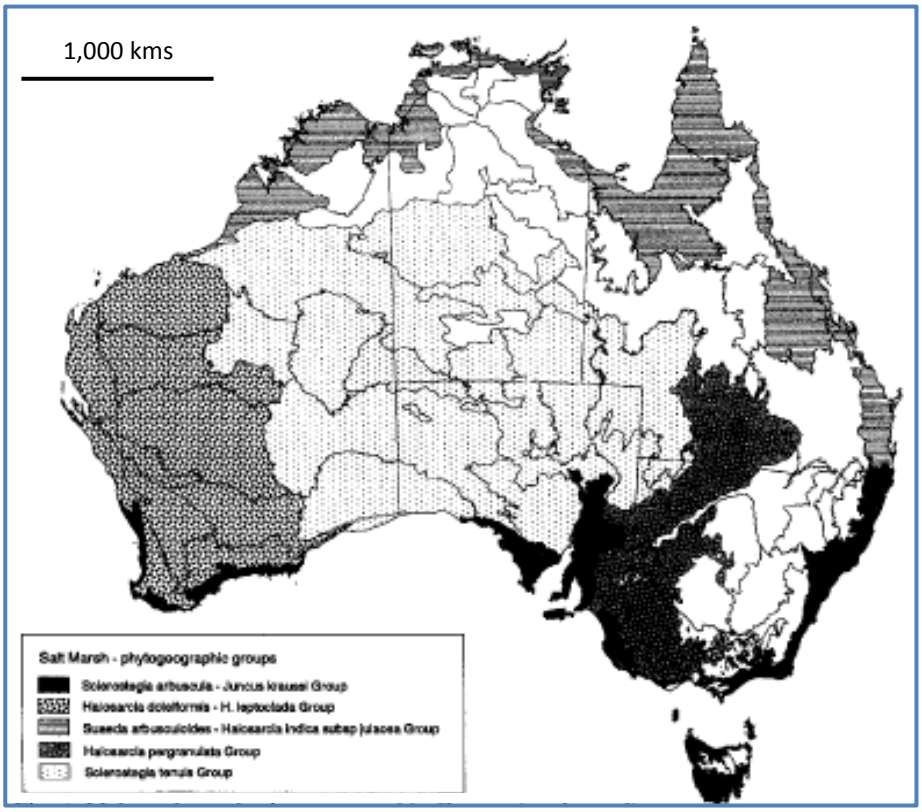

Figure 1.28: Major saltmarsh phytogeographic Groups for Australia. **Source:** Bridgewater and Cresswell (2003). **Note:** this map resolution is of poor quality, however, it is the best that is available.

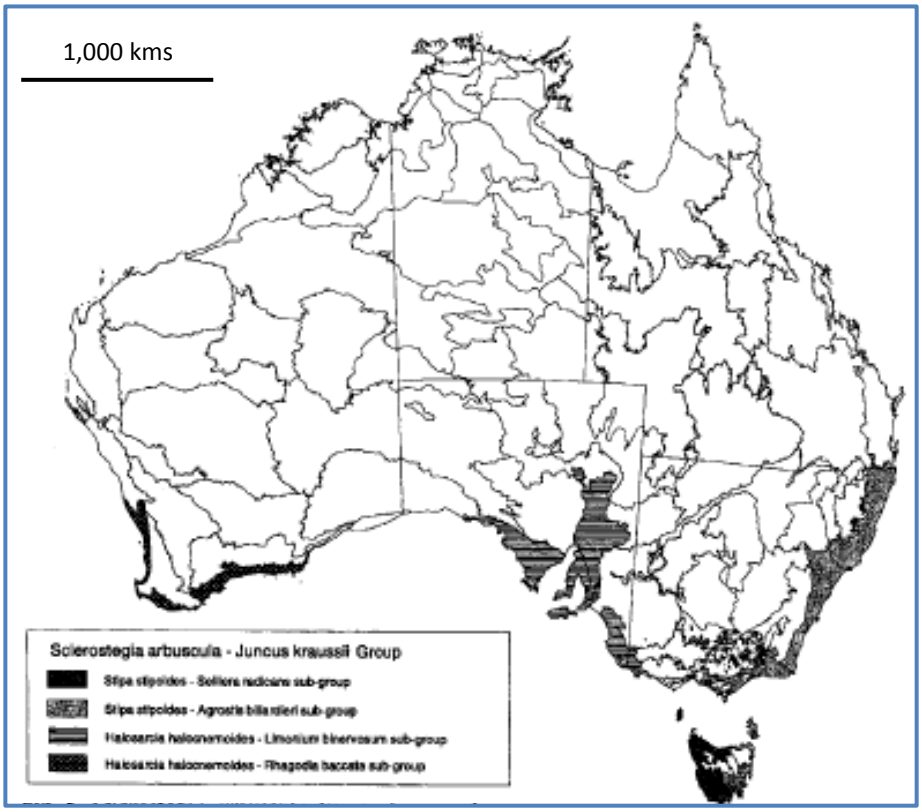

Figure 1.29: *Sclerostegia* (now *Tecticornia) arbuscula-Juncus kraussii* Group. **Source:** Bridgewater and Cresswell (2003). **Note:** this map resolution is of poor quality, however, it is the best that is available.

A later study by Saintilan (2009c) used a more recent version of AVH, which then held records for 103 saltmarsh species, and applied a cluster analysis to group coastal IBRA bioregions by plant species occurrence. The resulting dendrogram provided the basis of

similarity/dissimilarity of bioregions based on presence or otherwise of saltmarsh plant species. When these results were applied to the AVH data, the Australian continent was divided into a northern and southern region based on approximately the 23° parallel. The two divisions were further regionalised along coastal orientation, for example, northeast (NE), southwest (SW) (Figure 1.30).

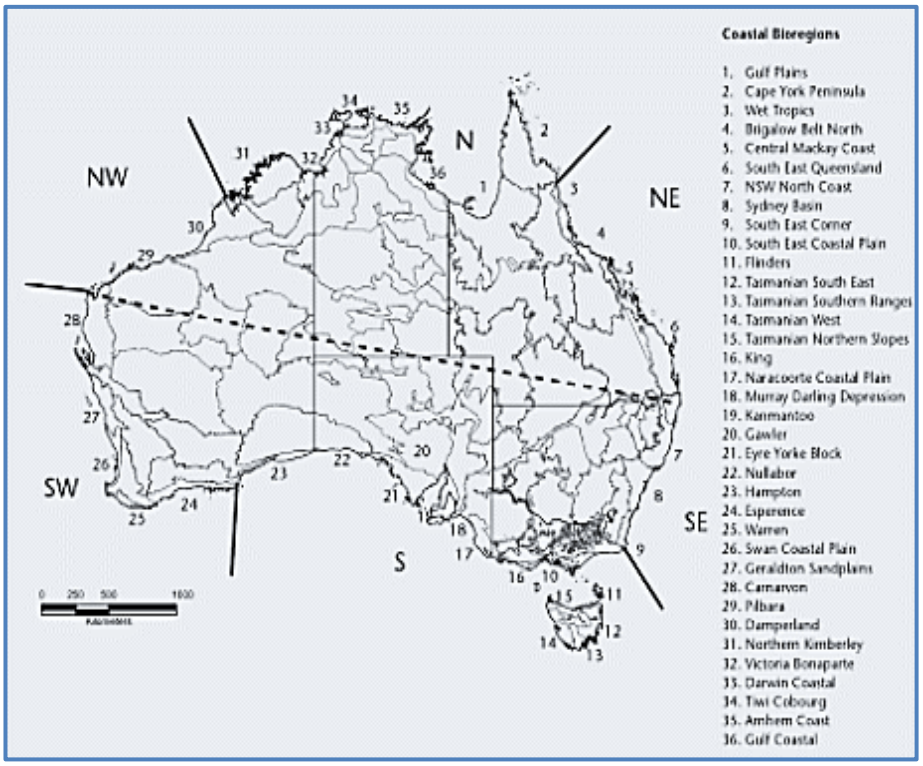

Figure 1.30: Coastal IBRA bioregions with saltmarsh biogeographic provinces identified by cluster analysis. **Source:** Saintilan (2009c).

Note: the dashed line divides the Australian continent into two divisions, each further divided into three regions each.

Saintilan (2009c) concluded his work with two key recommendations:

- The generation of a plant species list by Australian estuaries. This would document at fine scale the presence of individual saltmarsh plant species, and further, identify endangered or threatened species within individual estuaries. Information can then be provided to local NRM groups to instigate proper and coordinated attempts at conservation of coastal saltmarshes threatened plants species and vegetation communities; and
- The study of "… ecophysiological adaptions and ecological requirements of Australian saltmarsh plants …" (p. 36). There is importance in understanding the impacts of freshwater inundation on halophytic plants when assessing the diversion of freshwater into estuaries and drainage modifications within or adjacent to these highly sensitive areas (Saintilan 2009c).

1.10.3 Tasmania

Tasmania has a cool temperate climate that excludes the presence of mangroves, probably as a result of wintertime frosts (Kirkpatrick 1981). Native coastal saltmarshes are found in the southeast, east coast, Flinders and King Islands and the far north west of the island (see Figure 1.2, page 1.5). Pioneering Tasmanian saltmarsh research was conducted by Curtis and Somerville (1947) on the botanical and historical aspects of Boomer Bay on the Tasman Peninsula. Other early work focused on intertidal ecology, principally algae (Guiler 1949, 1952a, 1952b, 1952c), and the distribution, mapping and vegetation of saltmarshes (Glasby 1975; Kirkpatrick & Glasby 1981). Work on benthic fauna, vegetation and soil factors continued into the 1980s and 1990s (Marsh 1982; Richardson *et al.* 1991; Wong *et al.* 1993; Richardson & Mulcahy 1996; Richardson *et al.* 1997, 1998). A thesis by Gouldthorpe (2000) researched the impacts of drainage and grazing on Derwent River marshes and recently an extensive project identified changes in the extent and community composition of southeast Tasmanian saltmarshes (Prahalad 2009). The real and projected impacts of climate change have also received attention (Mount *et al.* 2010; Prahalad *et al.* 2011), and work by Prahalad, in the period 2010-2014, saw completion of coastal saltmarsh mapping in all three NRM regions of Tasmania. Finally, studies by Aalders (2014), Prahalad *et al.* (2015), Prahalad and Kirkpatrick (in press) and others are all now beginning to fill gaps in the knowledge base of Tasmanian coastal marshes.

Nevertheless, no studies have explored coastal saltmarsh regionalisation in Tasmania and their inter-relationships between various edaphic factors and climate variables.

1.11 Structure of thesis

This thesis consists of eight chapters. As the study encompassed several major saltmarsh aspects (vegetation communities, soil types, vegetation and soil type relationships, edaphic factor relationships, soil carbon content, salinity variations, and important individual plant species tolerance to significant edaphic factors), the thesis has been structured in a way to allow each aspect to be fully addressed. Each chapter is presented independently, and each is inclusive of an introduction, methods, results (reported comprehensively) and discussion (including the use of narrative descriptions, figures, tables and charts) followed by a conclusion.

Chapter 2 proposes in a thorough manner, a definition for Tasmanian coastal saltmarshes and provides details (by way of maps and tables) of all sites used in this study.

Chapter 3 presents the current vegetation classifications (viewed at a broad scale) and describes a state-wide vegetation assessment and methodology by statistical analysis of vegetation classification (viewed at a fine scale). It proposes eight new vegetation communities accompanied by a vegetation community identification key suitable for field-based ecological studies and observations within Tasmanian coastal saltmarshes. Field tests of the draft vegetation community identification key by an untrained observer determined the accuracy of the key, which led to improved identification features of the proposed and final vegetation community key. To conclude, vegetation communities were aligned to various natural regionalisation types to determine the best fit.

Chapter 4 describes a state-wide soil assessment and methodology by statistical analysis of soil type groups based on edaphic factors independent of vegetation. It aligns those results with selected types of natural regionalisations to determine which regionalisation provides a best fit of coastal saltmarshes. Finally, it aligns the new vegetation communities defined in Chapter 3 with soil types and provides a soil type description based on each vegetation community.

Chapter 5 investigates the carbon content of Tasmanian coastal saltmarsh soils. It proposes a useful conversion formula from loss on ignition at 550^{o}C to soil organic carbon/total carbon. Additionally, a suitable conversion is proposed for each of the proposed eight vegetation communities. Finally, a value of sequestered carbon in Tasmanian coastal saltmarshes was determined, thus highlighting the value of coastal saltmarshes in the context of conservation.

Chapter 6 focuses on the tolerance of key saltmarsh plant species to various edaphic factors and climate variables. The chapter concludes with a method of identifying suitable key pioneer plant species for saltmarsh restoration once key edaphic and climate attributes have been identified. It also provides decision making tools in the form of reusable charts to assist saltmarsh restoration.

Chapter 7 investigates the impact of increasing salinity due to sea-level rise and decreasing salinity from increased rainfall events because of climate change on several

vegetation communities. This investigation was conducted as an open air, natural environmental field trial, no modifications to plots of any kind were undertaken (other than regular treatment); consequently, all plots were subject to similar precipitation, evaporation, temperature and sunshine.

Chapter 8 is a synthesis of all the preceding chapters, drawing chapter threads together in a conclusion that shows that Tasmanian coastal saltmarshes are generally not a reflection of any natural regionalisation, and that IMCRA, in the Tasmanian context at least, is a somewhat useful tool in delineating Tasmania's coastal saltmarshes.

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1.13 Appendices

1A.1 Description of IBRA5.1 regions.

1A.2 Description of IMCRA mesoscale regions.

1A.3 Strengths and weaknesses of individual regionalisation schemes.

1A.1 Description of IBRA 5.1 regions

Table 1A.1: IBRA 5.1 – Coastal Tasmanian regional descriptions. **Source:** (Environment Australia (2000)). Table is ordered by region, clockwise from NE.

Code	Region	Region description
FLI	Flinders	Moist and dry subhumid warm coastal plains and granitic island chain comprised of Furneaux islands and coastal north-eastern Tasmania. Devonian granites dominate elevated areas of subregion forming low rugged ranges; overlain by shallow stony/gravelly gradational or duplex soils carrying *Eucalyptus amygdalina* open forest and woodland with *E. nitida* open heath on higher peaks. Quaternary/Tertiary materials overlain by deep sandy soils typify extensive lowland plains, coastal deposits and dunes. Coastal plains heavily modified by agriculture (grazing).
TSE	Tasmanian South East	Subhumid cool to warm coastal plains on a highly indented coastline, bordered inland by low mountain ranges formed from Jurassic dolerite and Permo-Triassic sediments. Soils predominantly clay to sandy loams. Vegetation predominantly dry sclerophyll forest, patches of wet sclerophyll forest, relict rainforest, coastal heath and dry coniferous forest. Extensive areas converted to improved pasture and cropland. Land use primarily agriculture (grazing) and forestry.
TSR	Tasmanian Southern Ranges	Humid cool mountainous tract of central southern Tasmania. Permo-Triassic sediments and Jurassic dolerite mantled with sandy to clay loams. Heavily forested, grading from mixed forest, wet sclerophyll forest and patches of rainforest in uplands to dry sclerophyll forest on coastal lowlands. Land use primarily forestry and agriculture (grazing and cropping).
TWE	Tasmanian West	Perhumid cold lowlands, low hills and low ranges, comprising most coastal and inland western Tasmania. Folding and subsequent erosion resulted in rugged dissected inland ranges dominated by Precambrian and Cambrian rocks supporting oligotrophic acid peat soils or shallow organic horizons over deep mineral profiles. From 300 metres elevation, a discontinuous, coastal, plain slopes westward to ocean. Vegetation a complex mosaic of rainforest *(Nothofagus),* buttongrass *(Gymnoschoenus sphaerocephalus)* moorlands and *Eucalyptus nitida* scrub. Principal land uses conservation, mining and forestry.
KIN	King	Perhumid warm coastal plains and low hills comprising King Island and the north-west tip of Tasmania. Region of subdued topography and low relief. Precambrian metamorphic rocks overlain by diverse soils, including recent marine deposits covered by deep sandy profiles supporting extensive *Eucalyptus obliqua* open forest and *Nothofagus cunninghamii* closed forest. *Acacia melanoxylon* closed forest and *Melaleuca ericifolia* closed forest occur on poorly drained low-lying sites. Vegetation of King Island substantially degraded by clearing and burning following European settlement.
TNS	Tasmanian Northern Slopes	Humid warm coastal plains and deeply dissected lowland hills rising from Tasmania's central north coast to foot of the Central Highlands, rolling hilly plateau. This geologically diverse region comprises complexes of Cambrian and Pre Cambrian-metasediments, basic-intermediate volcanics, and post-Carboniferous sediments with soils ranging from deep basaltic loams to acidic sandy coastal soils. Vegetation is wet and dry sclerophyll forest with coastal heaths and some rainforest which progressively replaces the sclerophyll forest in west. Native vegetation replaced by improved pasture and cropland throughout lowlands. Land use primarily forestry and agriculture (cropping).

1A.2. Description of IMCRA mesoscale regions

Table 1A.2: Description of Tasmania's IMCRA meso-scale bioregions for Figure 1.25 (map). **Source:** IMCRATG (1998). Additional regional descriptions are available in IMCRATG (1988) pages 59-101. Table ordered by region, clockwise from northeast. **Note:** region CBS not included in this table.

Region Code and Number	Region Name and jurisdiction affiliation	Description
TWO 52	Twofold Shelf – TAS/VIC/ NSW	**Location**: East of Wilsons Promontory and north to Tathra (36°48'S), including the Kent Group (around 39°25'S). **Remarks**: Sub-maximally exposed coastline with long sandy beaches broken by rocky headlands, numerous coastal lagoons. Moderate tidal range ~ 2m. Mean annual sea-surface temperature reflects influence of warmer waters brought into Bass Strait by East Australian Current. Variable wave energy.
FLI 49	Flinders – TAS/VIC	**Location**: Eastern entrance to Bass Strait and including Wilsons Promontory, Furneaux Group of islands (but not the Kent Group). **Remarks**: Rapid changes in offshore gradient. Granitic coastline exposed to submaximal swells on east-facing shores of Flinders Is. and moderate to low swells elsewhere. Sandy beaches moderate length with seagrass beds prevalent in shallow water. High tidal range >3m, strong tidal currents. Sea-surface temperature representative of Bass Strait waters. Waves highly variable.
FRT 48	Freycinet – TAS	**Location**: Tree Point to Cape Bernier. **Remarks**: Sub-maximally exposed coastline, approximately equal areas of rocky headland and sandy beach; many coastal lagoons. Moderate tidal range >1.5m. Cool water, sub-tropical mixing.
BRU 47	Bruny – TAS	**Location**: Cape Bernier to Southport, including Bruny Island. **Remarks**: Highly-dissected coastline with extensive embayments protected from submaximal swell by islands and peninsulas. Low tidal range » 1m. Endemic plants and animals.
DAV 46	Davey – TAS	**Location**: Southport to Svenor Point, including Port Davey and Bathurst Harbour. **Remarks**: Very exposed coastline with extensive rocky headlands separated by short sandy beaches. Low tidal range >1m. Biotically depauperate. Cold water.
FRA 57	Franklin – TAS	**Location**: Svenor Point to Cape Grim, including Macquarie Harbour. **Remarks**: Extremely exposed open coastline with long sandy beaches broken by rocky headlands. Moderate tidal range >5m.
OTW 44	Otway – TAS/SA/VIC	**Location**: Cape Jaffa to slightly north of Apollo Bay and including King Island, narrow band across the western entrance of Bass Strait, including parts of the Fleurieu Group and Woolnorth Point. **Remarks**: Very steep to moderate offshore gradients. High wave energy. Currents generally slow, but moderately strong through entrance to Bass Strait. Cold temperate waters subject to nutrient rich upwellings.
BGS 45	Boags – TAS	**Location**: Near Kangaroo Island to Tree Point (Little Musselroe Bay). Includes part of the Fleurieu Group (Robbins and Three Hummock islands). **Remarks**: Sheltered open coastline with long sandy beaches broken by rocky headlands that extend under sand in relatively shallow depths (normally <20m). High tidal range >3m.

1A.3 Strengths and weaknesses of individual regionalisation schemes

Table 1A.3: Strengths and weaknesses of individual regionalisation schemes.

Regionalisation	Strengths	Weaknesses
Weather forecast districts (Bureau of Meteorology)	1. Temperature and rainfall useful indicators of plant species presence	1. Land district boundaries meet local (human) community expectations; 2. Coastal districts bounded by reference points (geo-markers); 3. Coastal district boundaries consensus position suitable for commercial fishers; 4. Coastal flora and fauna did play a role in formulating district boundaries.
Estuarine classification (Edgar *et al.*, 2000)	1. Boundaries based on microbenthic invertebrates; 2. Estuary classification based on catchment size, estuarine drainage, summer and winter salinity, presence or otherwise of a seaward barrier.	1. Lacks any consideration of floristics
Geographical regions (Edgar *et al.*, 1999)	1. Positions saltmarshes in the landscape on a very broad scale.	1. Regional boundaries determined on a non-natural basis; 2. Delineation based on a subjective assessment of coastal geographical aspects; 3. Misses the micro-aspects of individual saltmarshes at a fine scale.
Vegetation and floristics (Specht *et al.*, 1974; Jackson, 1974)	1. Vegetation a dominant feature of coastal saltmarshes.	1. Terrestrial based, generally on geomorphological and floristic basis to nine coastal/inland regions; 2. Broad-brush approach taken; 3. No consideration of coastal aspects and plant species presence at a fine scale.
Interim Biogeographic Regionalisation for Australia (IBRA)	1. Developed through a consensus of all Australian jurisdictions; 2. Based on major attributes of climate, lithology/geology, landform, vegetation, flora and fauna and land use; 3. Regional boundaries determined by natural attributes, not human based attributes; 4. Boundaries updated regularly when new data is available; 5. Available in sub-regions, these focus on a finer local scale; 6. Established as a conservation planning tool at national and regional levels.	1. Terrestrial based regions only; 2. Lacks coastal/marine interface data and knowledge.

Regionalisation	Strengths	Weaknesses
Interim Marine and Coastal Regionalisation of Australia (IMCRA)	1. Developed through a consensus of all Australian jurisdictions; 2. Based on major attributes of biophysical (sponges, fishes, corals, sea-grasses) and physical (bathymetry, coastal geomorphology, sediments, currents, water chemistry, water temperature); 3. Regional boundaries determined by natural attributes, not human based attributes; 4. Established as a conservation planning tool for marine protected areas at national and regional levels; 5. To provide regional framework for planning sustainable resource development and biodiversity conservation.	1. Coastal marine based regions only; 2. Lacks coastal/marine interface data and knowledge.

Chapter 2

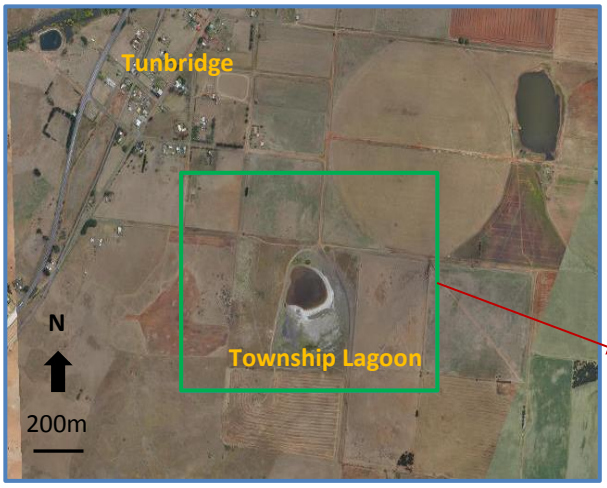
Defining Tasmanian coastal saltmarshes and description of study sites

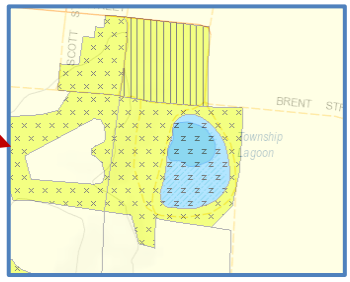
Chapter 2 – Table of Contents

Chapter 2: Definition of Tasmanian coastal saltmarshes and detail of study sites

2.1 Classifying Tasmanian coastal saltmarshes

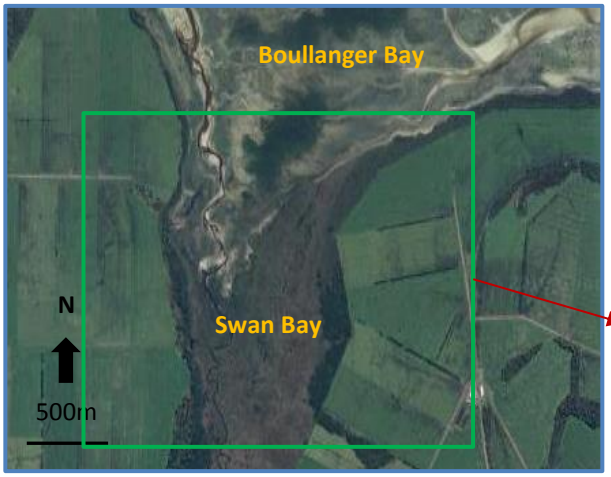
Though determined by biophysical rules, saltmarshes are distributed in a non-regular manner. They can be categorised as either inland (well distant from any marine waters; for example, salt flats and vegetated marsh plains of Township Lagoon, Tunbridge, central Tasmania – Figure 2.1) or coastal (connected or adjacent to the marine environment, e.g. Swan Bay in Boullanger Bay, north west Tasmania – Figure 2.2) (Department of Primary Industries, Parks, Water and Environment 2014) (DPIPWE). As this study does not consider inland saltmarshes, this category is not considered further.

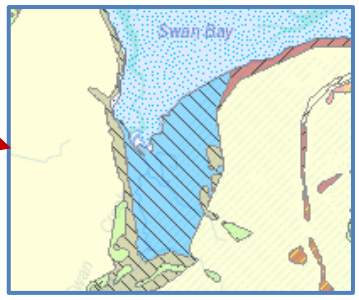




ASS = Saline succulent herbland

Figure 2.1: Inland saltmarsh – Township Lagoon at Tunbridge – the nearest coast is 50kms distant. The lagoon and surrounding area have been classified as saltmarsh under TASVEG (see below). **Source:** DPIPWE (2018a).





ARS = Saline sedgeland /rushland

Figure 2.2: Coastal saltmarsh – Swan Bay within Boullanger Bay, north west Tasmania. The embayment has been classified as saltmarsh under TASVEG (see below). **Source:** DPIPWE (2018a).

In an ecological/physical sense Tasmanian coastal saltmarshes can be classified as being either functional, semi-functional, or non-functional (Figure 2.3 – see Flowchart, following page).

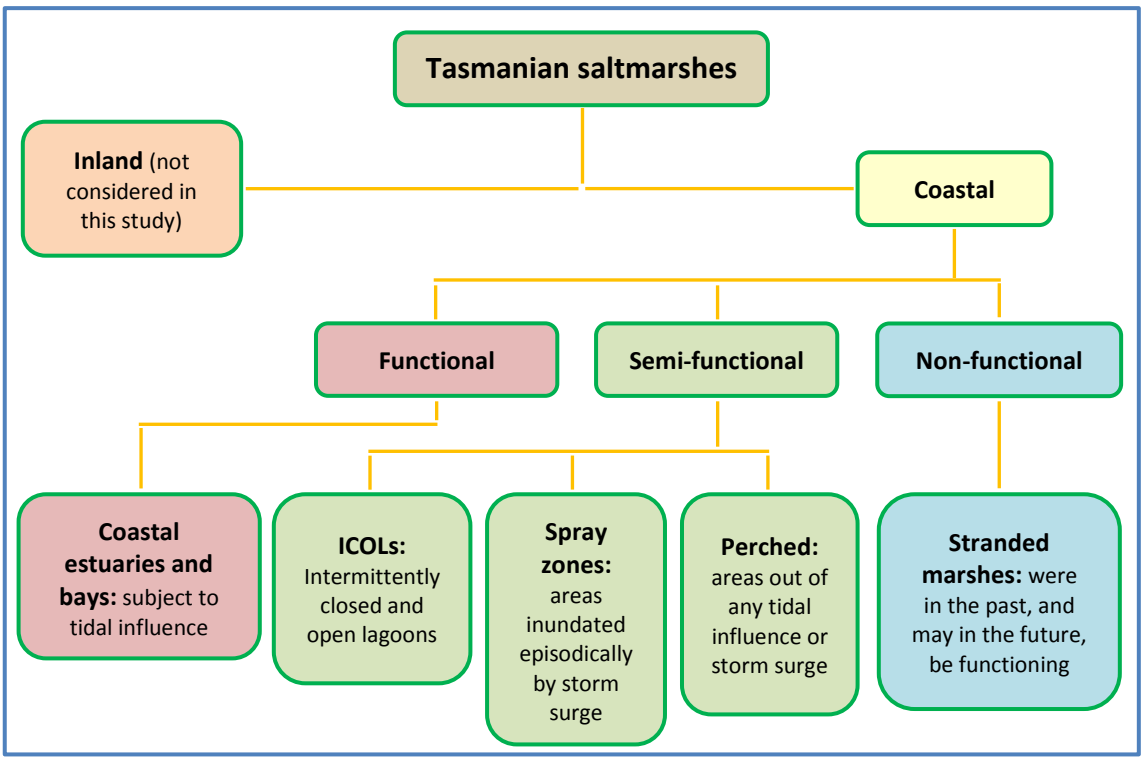


Figure 2.3: Diagram illustrating the complexity of Tasmanian coastal saltmarshes.

Location of sites used as examples in following discussion of functional, semi-functional and non-functional marshes are displayed in Figure 2.5 (following page).

2.1.1 Functional marshes

A functional saltmarsh is one that is influenced by diurnal (one high tide and one low tide every lunar day) or semidiurnal (two high tides and two low tides each lunar day) tides on a frequent basis (Figure 2.4). In either case, the saltmarsh is frequently replenished with marine waters that cover various portions of the marsh and fill channels and creeks, these draining during a falling/low tide (Long & Mason 1983; Adam 1990).

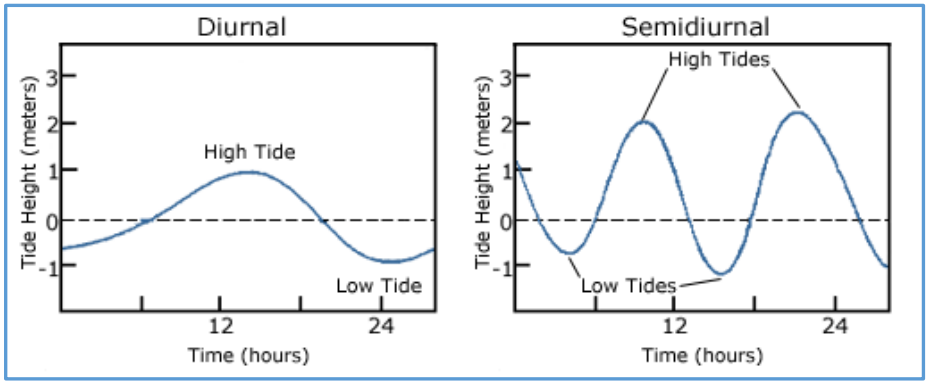


Figure 2.4: Examples of diurnal and semidiurnal tide patterns. **Source:** National Oceanic & Atmospheric Administration (2018).

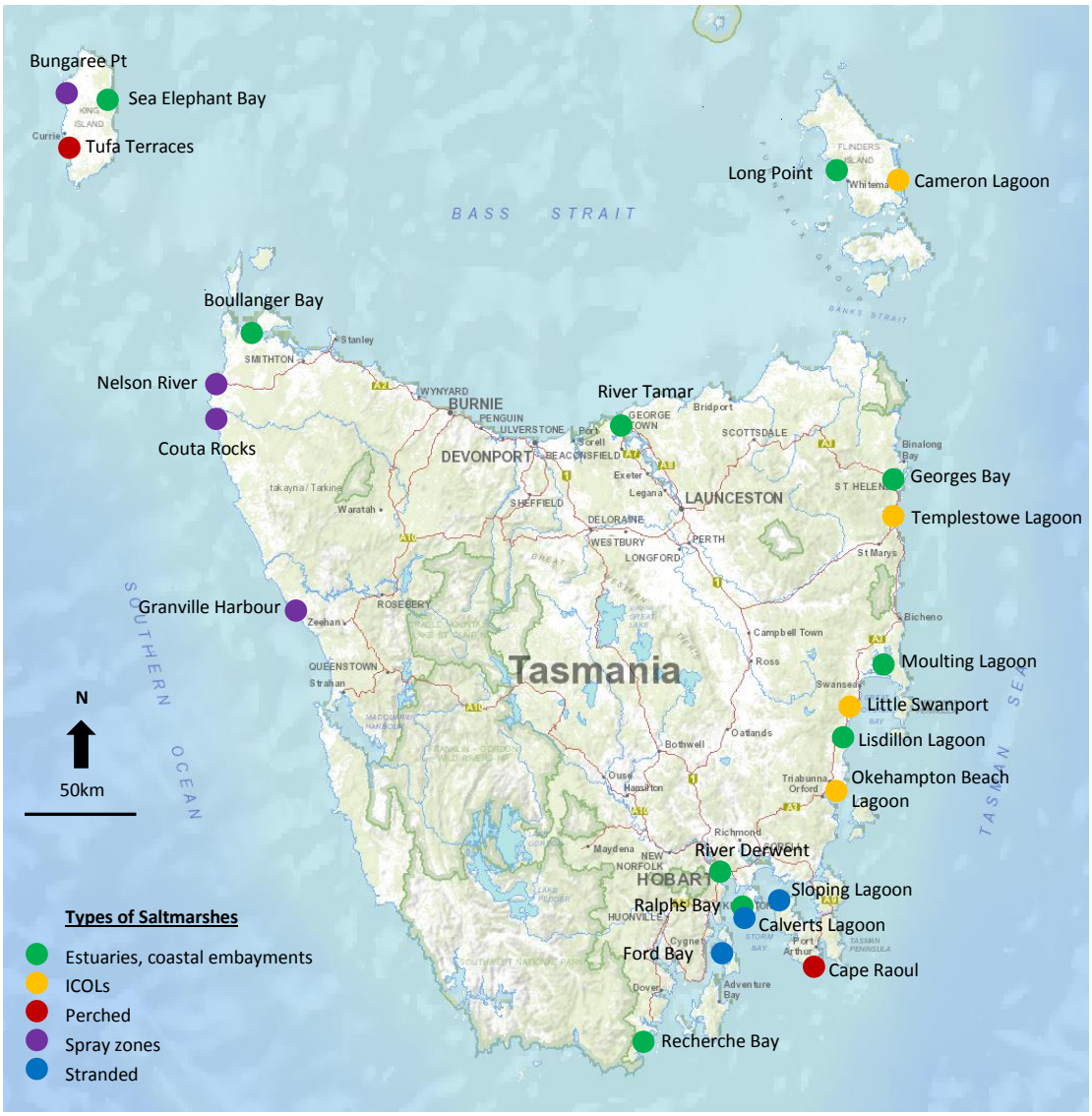


Figure 2.5: Location of sites incorporated in this discussion by classification/type. **Source:** DPIPWE (2018a).

A basic example of a functional saltmarsh is an estuarine marsh, into which one or more streams or rivers flow freely and there is an unobstructed connection to the open sea (Figure 2.6). Estuarine saltmarshes are found on most Tasmanian coasts, particularly the south east, east and northern coasts (Prahalad 2014). Examples include the Derwent and Tamar estuaries, Little Swanport, Moulting Lagoon, Georges Bay and Sea Elephant Bay (King Is.). Embayments to can contain saltmarshes (Figure 2.7), examples include, Boullanger Bay, Ralphs Bay and Recherche Bay. Floristically, functional saltmarshes have a high species richness and generally encompass the full range of plants from the highly salt tolerant at the marine interface, to those plants at the terrestrial interface being somewhat less salt tolerant.

Figure 2.6: Functional estuarine saltmarsh – Little Swanport estuary – Little Swanport River, Ravensdale Rivulet and White Hut Creek are the principal flows entering the estuary. Many bays and inlets within the estuary have saltmarsh habitats; the unrestricted exit to the open sea is at the top right hand corner. **Source:** DPIPWE (2018a).

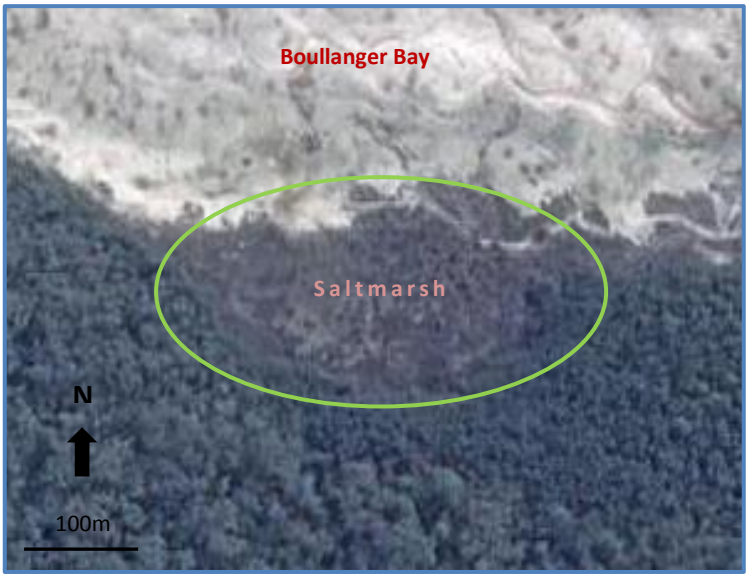


Figure 2.7: Functional embayment saltmarsh in Boullanger Bay (far NW coast). There is no tidal restriction allowing marine waters to freely enter and leave the embayment during each tidal cycle. (Note: this aerial image was taken during low tide.)
Source: DPIPWE (2018a).

2.1.2 Semi-functional marshes

A semi-functional saltmarsh is one that has a marine water influence yet is not frequently/regularly inundated by marine waters. There are three key examples of a semi-functional marsh: a) intermittently closed and open lagoon known as an ICOL, b) perched marsh, and c) spray zone.

Intermittently closed and open lagoons are found where a semi-permanent barrier, such as a sandbar, precludes regular flushing of the marsh. This barrier can be in place for long periods of time and is either removed or breached during storm events, or when sufficient water levels within the marsh are able to rupture the "sand levee" and allow an ingress of marine waters (Weir *et al.* 2006). Over time, the sand barrier will again begin to close restricting regular tidal flows and in time finally close for a period before being breached again (Figures 2.8 and 2.9). ICOLs are generally found on Tasmania's east coast and on the eastern side of Flinders Island (Edgar *et al.* 1999; Prahalad 2014). Examples include, Okehampton Beach Lagoon, Lisdillon Lagoon, Templestowe Lagoon and Cameron Lagoon on Flinders Island.

Figure 2.8: Semi functional saltmarsh – an ICOL – Eighty Acre Creek Lagoon at Grindstone Bay showing the mouth open to the sea; aerial image of 7 January 2017. **Source:** Google Earth (2018).

Figure 2.9: Semi functional saltmarsh – an ICOL – Eighty Acre Creek Lagoon at Grindstone Bay showing the mouth closed to the sea; aerial image of 31 March 2014. **Source:** Google Earth (2018).

Perched sites are those areas that are subject to aeolian borne salt inputs and deposits yet are positioned in the landscape where there can be no tidal or storm surge inputs due to being sited, for example, on cliff tops (Figures 2.10 and 2.11). Perched marshes are generally restricted to coastlines that experience strong winds, such as Tasmania's west coast and the west coast of King Island. Examples include an unnamed cliff top lagoon on Cape Raoul and Tufa Terraces (Boggy Creek) on King Island. The following figures highlight the example on Cape Raoul.

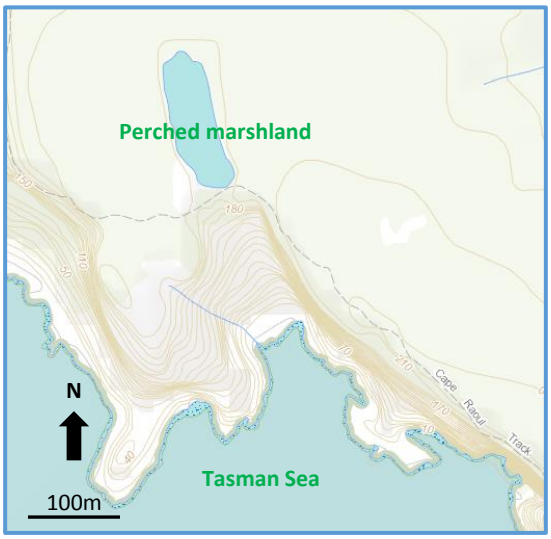


Figure 2.10: Semi-functional saltmarsh – perched marsh (unnamed) on Cape Raoul (Tasman Peninsula), Tasmania. Site is not connected to the sea, it is only subject to aeolian borne salts. Topographical map. **Source:** DPIPWE (2018a).

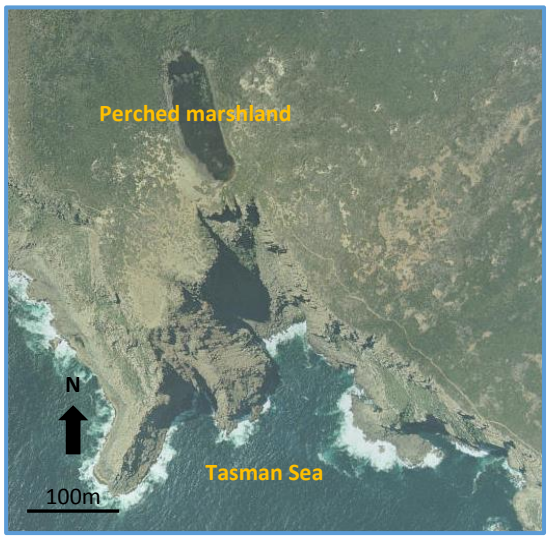


Figure 2.11: Semi-functional saltmarsh – perched marsh (unnamed) on Cape Raoul (Tasman Peninsula), Tasmania. Site is not connected to the sea, it is only subject to aeolian borne salts. Aerial image (date unknown). **Source:** DPIPWE (2018a).

Here the perched marshland is approximately 200 metres above sea-level, precluding any connection to the sea. Yet, halophilic plant species such as *Sarcocornia quinqueflora, Sarcocornia blackiana, Disphyma crassifolium* and *Selliera radicans* are very much present at the site (ground truthed February 2018). Cape Raoul is frequently battered by very strong southerly and south-westerly winds (Bureau of Meteorology 2016) (BOM) and salt laden sea spray is funnelled up a steep gully (to the south of the small lagoon) and over the site (personal observations). Sufficient aeolian borne salt is deposited in the area to sustain a healthy, halophilic vegetation community (Figures 2.12 to 2.14 – see following page). Additionally, soils analysed from this site show a salinity level (~20‰) that is well within the salinity range for sites containing similar floristics.

Figure 2.12: Semi-functional saltmarsh – perched saltmarsh, an unnamed lagoon on Cape Raoul, Tasman Peninsula.

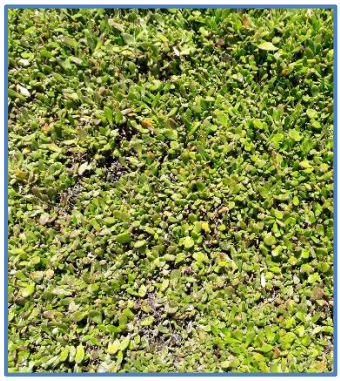


Figure 2.13: *S. radicans* at lagoon on Cape Raoul.

Figure 2.14: *S. quinqueflora* and *D. crassifolium* at lagoon on Cape Raoul.

Spray zone marshes are those subject to storm surge, the occasional high astronomical tide and aeolian borne salt deposits (Kitchener & Harris 2013) and are generally out of reach of normal high tides. Spray zone marshes are restricted to Tasmania's west coast and the west coast of King Island, locations subject to very strong winds – The Roaring Forties – and high storm waves. Example locations include Granville Harbour, Couta Rocks (Figures 2.15 and 2.16), Nelson Bay (Figures 2.17 to 2.19) and Bungaree Point (King Island). Wind driven storms, particularly during winter, and high astronomical tides provide episodical marine inundation, which in turn sustains healthy communities of salt tolerant plants such as *S. quinqueflora, S. radicans, Distichlis distichophylla, Samolus repens* and in the case of Bungaree Point (King Island), *Tecticornia arbuscula.*

Figure 2.15: Semi-functional saltmarsh – spray zone at Couta Rocks. Site subject to high astronomical tides, storm surge and aeolian borne salts. **Photos courtesy:** Vishnu Prahalad.

Figure 2.16: Vegetation community of spray zone at Couta Rocks – mix of *S. quinqueflora, D. distichophylla* and *Atriplex prostrata* (left side).

Figure 2.17: Semi-functional saltmarsh – spray zone at Nelson Bay. Site is subject to high astronomical tides, storm surge and aeolian borne salts. Vegetation community comprises *S. quinqueflora, D. distichophylla* and *Austrostipa stipoides.* **Photo courtesy:** Vishnu Prahalad.

Figure 2.18: Vegetation at Nelson Bay spray zone – *A. stipoides* and *Ficinia nodosa.* **Photo courtesy:** Vishnu Prahalad.

Figure 2.19: Vegetation at Nelson Bay spray zone – *S. quinqueflora* subsp. *tasmanica* and *Lobelia anceps* (purple flowering species). **Photo courtesy:** Vishnu Prahalad.

2.1.3 Non-functional marshes

A non-functional saltmarsh is one that contains saltmarsh plants but doesn't have a free flowing stream passing through it, nor is it connected to the sea. Although a non-functional saltmarsh does not have a sea-based linkage, they do express ecological

functions which are similar to other types of coastal saltmarshes. An example of this type of marsh is a stranded marsh, one that had in the past been connected to the open sea, but coastal processes have created a barrier that has for the time being, permanently closed any observed coastal connection. It is possible that future sea-level rises will allow these types of saltmarshes to be re-connected to the sea and become fully functioning again. Tasmania has several stranded marshes, situated mainly on the south east coast. Examples include Sloping Lagoon (Tasman Peninsula), Calverts Lagoon (South Arm), Rushy Lagoon (Sandford) and Ford Bay (Bruny Island).

Case studies

Ford Bay (Bruny Island)

The following figures present the case study for Ford Bay on Bruny Island (Figures 2.20 to 2.26). The area in question was ground truthed during December 2017 and contains many saltmarsh tolerant plants such as *S. radicans, Juncus kraussii* and *S. repens*. This suggests that sometime in the past this area was possibly inundated by tidal influences and was a functioning saltmarsh. It is unclear whether the site was an ICOL or an embayment saltmarsh. Two possible scenarios suggest why a connection to the sea may have been lost: a) northerly generated wave action (BOM 2018a) formed a sand barrier approximately 0.5 to 1.0 metres high, preventing tidal influence from inundating the area, or b) following the last glacial period, sea-levels rose higher (thus sustaining a functioning saltmarsh) and have subsequently fallen to current levels (Corbett 2014). In both cases, the area may have been functioning as a true saltmarsh before coastal processes (see Ralphs Bay case study below), or a fall in sea-level, cut connection to the sea. Analysis of present-day soils (as shown in Chapter 4) indicate sufficient salinity exists to sustain a healthy population of halophilic plants. Current salinity levels may be sustained by seepage from adjacent Ford Bay, however studies have not been undertaken to test this likelihood. Recent coastal inundation mapping for Tasmania, undertaken by the Department of Premier and Cabinet, predicts that by year 2050, this area will be inundated due to sea-level rise, and will be significantly impacted by storm surge events by 2100 (Lacey 2016; DPIPWE 2018b) (Figures 2.25 and 2.26). Should this eventuate, this non-functioning stranded marsh may once again become a fully functioning saltmarsh.

Figure 2.20: Tasmania and location of Bruny Island. **Source:** DPIPWE (2018a).

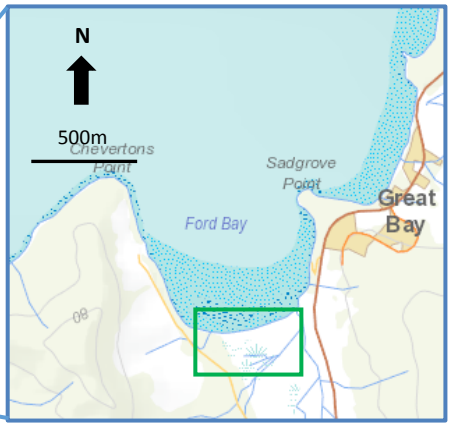


Figure 2.22 (above): Location of stranded saltmarsh Ford Bay (refer to Figure 2.23 – following page). **Source:** DPIPWE (2018a).

Figure 2.21 (left): Location of Ford Bay – Bruny Island. **Source:** DPIPWE (2018a).

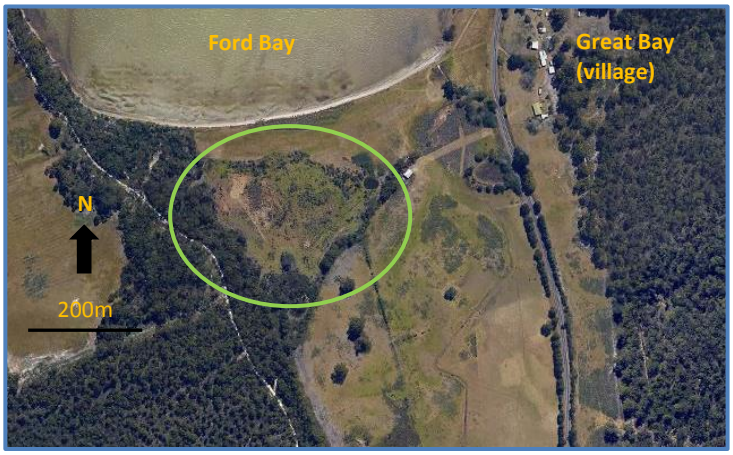


Figure 2.23: A stranded saltmarsh (green circle) at Ford Bay (at Great Bay), Bruny Island, aerial image date unknown.
Source: DPIPWE (2018b).

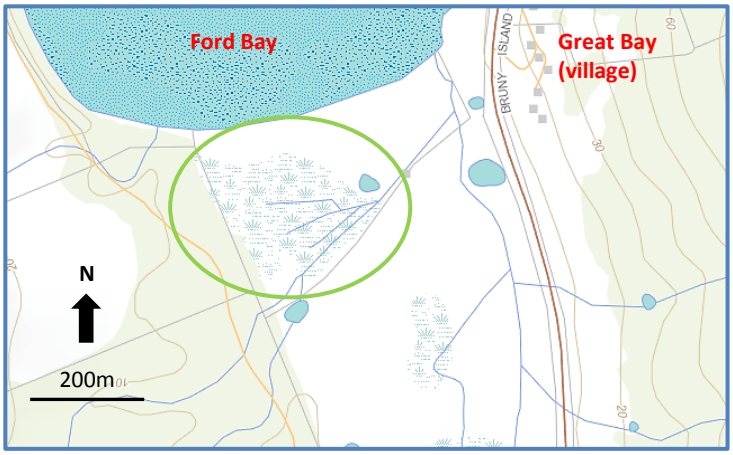


Figure 2.24: A stranded saltmarsh (green circle) at Ford Bay (at Great Bay), Bruny Island, topographical image. **Source:** DPIPWE (2018b).

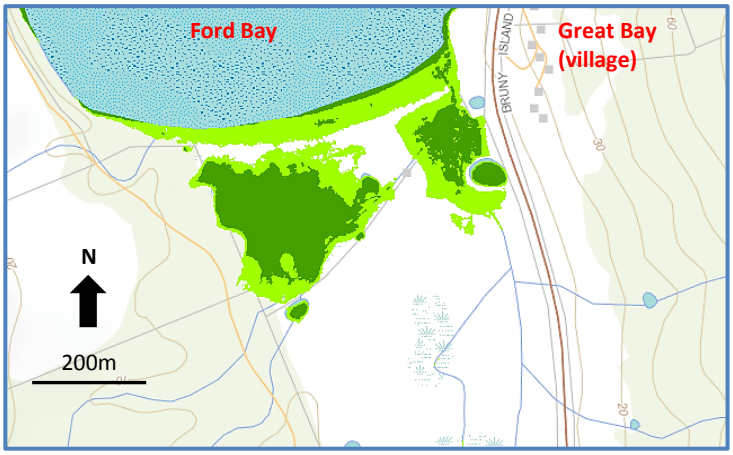


Figure 2.25: Ford Bay (at Great Bay), Bruny Island, topographical image displaying predicted sea-level rise years 2050 and 2100.
Source: DPIPWE (2018b).

Predicted Sea Level Rise 2100
Predicted Sea Level Rise 2050

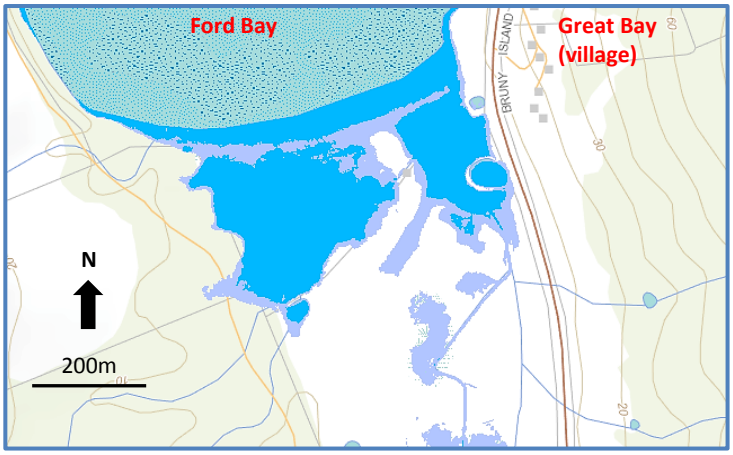


Figure 2.26: Ford Bay (at Great Bay), Bruny Island, topographical image displaying projected storm tide 1% AEP 2010, 2050 and 2100.
Source: DPIPWE (2018b).

AEP = Annual Exceedance Probability = 1 in 100 chance of being exceeded in any year.

Storm Tide 1% AEP 2010
Storm Tide 1% AEP 2050
Storm Tide 1% AEP 2100

Ralphs Bay (South Arm)

Another example is Ralphs Bay, located in the southern part of the Derwent Estuary on South Arm, it is somewhat comparable to that that of Ford Bay. However, it is still technically classified as a functioning marsh within a coastal embayment. Geographically, Ralphs Bay (Figures 2.29 to 2.31) is similar to Ford Bay in lying in an east/west orientation, facing north. It is impacted by north-westerly/northerly generated waves (BOM 2018c) that have a similar reach to those affecting Ford Bay on Bruny Island. This saltmarsh was ground truthed in March 2016 and has no active flowing stream connection to the sea. It is undergoing a contemporary coastal process of an accreting (in height) sand barrier that was highly likely experienced by Ford Bay in the past. The current sand barrier is of enough height (Figures 2.27 and 2.28) to preclude any tidal inundation, but low enough to allow storm surge waves to inundate the marsh to keep it in a functioning state. Additionally, it appears that the saltmarsh is also sustained by marine water seepage from the adjoining bay (personal observations).

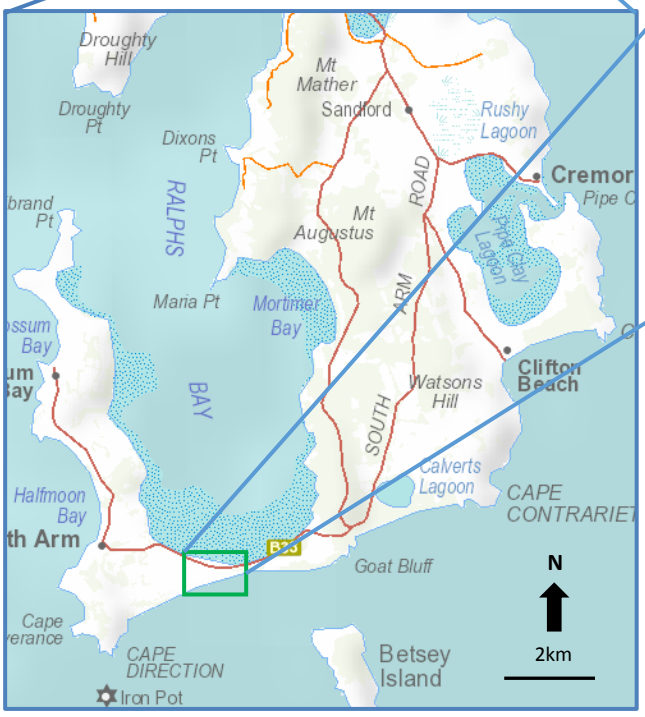
Figure 2.27: Coastal sand barrier at Ralphs Bay saltmarsh from marine angle looking southwest.

Figure 2.28: Coastal sand barrier at Ralphs Bay saltmarsh from top of dune looking west.

Floristically, the site is reasonably rich, currently supporting a healthy population of halophilic plants. Eleven plant species were recorded here, including *A. stipoides, Gahnia filum, Hemichroa pentandra, J. kraussii, S. repens* and *S. quinqueflora,* all plant species found throughout many Tasmanian fully functioning saltmarshes. Analysis of present-day soils (as shown in Chapter 4) indicate salinity levels range from 11‰ at the terrestrial edge to 32‰ in the lowest section of the marsh adjacent to the marine interface just inside the sand barrier. Salinity levels appear to be sustained by several factors: past high level of salt deposits, occasional storm surge (over the sand barrier) and seepage from the adjacent bay; studies, however, have not been carried out to support this. Similar to

Ford Bay, recent coastal inundation mapping for Tasmania has predicted that by year 2050 this area will be inundated due to sea-level rise, and considerably impacted by storm surge events by year 2100 (Figures 2.32 to 2.35) (Lacey 2016; DPIPWE 2018b). Should this eventuate, this currently functioning saltmarsh, which is slowly progressing to become a non-functioning saltmarsh, may once again become a fully functioning saltmarsh.

Figure 2.29: Tasmania and location of South Arm. **Source:** DPIPWE (2018a).



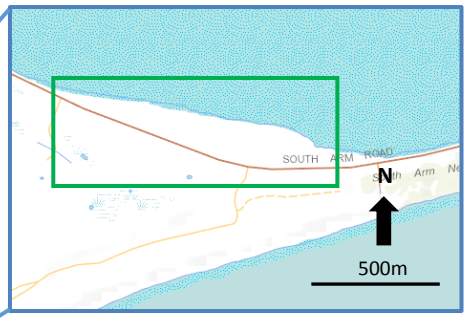


Figure 2.31 (above): Location of functional embayment saltmarsh Ralphs Bay (refer to Figure 2.32 – following page). **Source:** DPIPWE (2018a).

Figure 2.30 (left): Location of Ralphs Bay – South Arm. **Source:** DPIPWE (2018a).

Figure 2.32: Functional saltmarsh, an embayment (green circle), at Ralphs Bay (South Arm Road), South Arm, aerial image, date unknown. **Source:** DPIPWE (2018b).

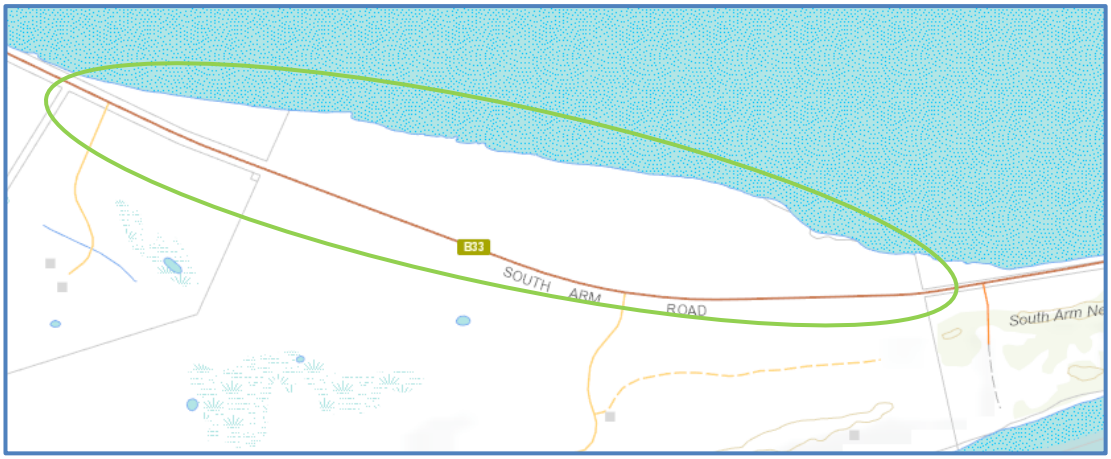


Figure 2.33: Functional saltmarsh, an embayment (green circle), at Ralphs Bay (South Arm Road), South Arm, topographical image. **Source:** DPIPWE (2018b).

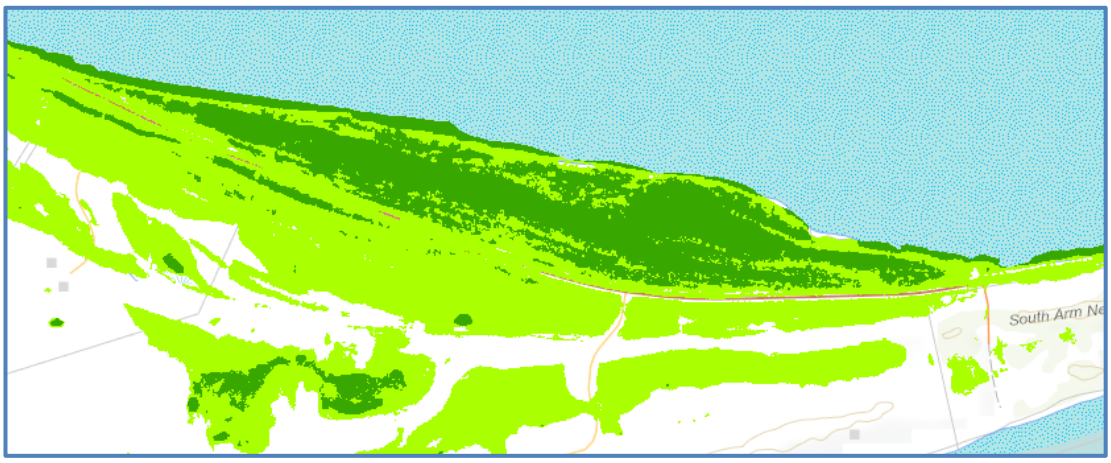


Figure 2.34: Ralphs Bay (South Arm Road), South Arm, topographical image displaying predicted sea-level rise by years 2050 and 2100. **Source:** DPIPWE (2018b).

Predicted Sea Level Rise 2100
Predicted Sea Level Rise 2050

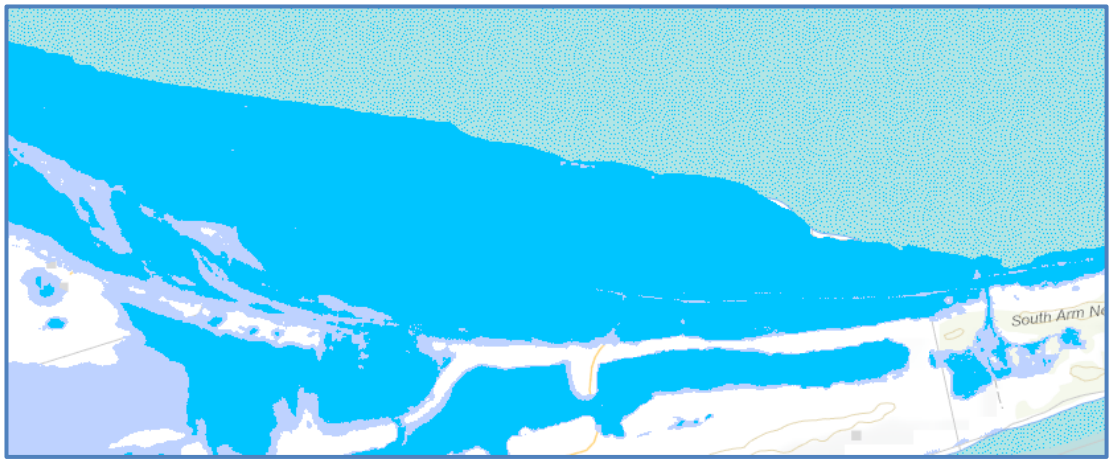


Figure 2.35: Ralphs Bay (South Arm Road), South Arm, topographical image displaying projected storm tide 1% AEP 2010, 2050 and 2100. **Source:** DPIPWE (2018b). **AEP** = Annual Exceedance Probability = 1 in 100 chance of being exceeded in any year.

2.1.4 Defining coastal saltmarshes – the EPBC Act

Coastal saltmarshes are listed under Commonwealth legislation[24] within the *Environment Protection and Biodiversity Act 1999* (EPBC Act), Section 266B, as a Threatened Ecological Community (Department of Environment and Energy n.d.). The EPBC Act is the Australian Government's key piece of environmental legislation that has over-arching powers over State based legislation when State based legislation is not as robust as Commonwealth legislation, or when State legislation does not exist. In the case of Tasmania, there is no current coastal saltmarsh definition, therefore the EPBC Act definition prevails. The Act defines Subtropical and Temperate Coastal Saltmarsh as "located in a coastal area and under regular or intermittent tidal influence and can include those lagoonal estuaries that are open intermittently, known as ICOLs (intermittently closed and open lagoons)". At a first pass, this definition appears to omit specific saltmarsh types that occur in Tasmania and floristics do not rate a mention. However, when key diagnostic features, survey guidelines and condition thresholds are analysed within the listing documents (Conservation Advice), the definition is somewhat misleading. In a Tasmanian context, the definition appears to omit important characteristics and other circumstances, such as:

[24] Follows: Department of Environment and Energy (n.d.): *Subtropical and Temperate Coastal Saltmarsh* Conservation Advice.

- Occurs on the coastal margins within estuaries and along coastal embayments and coasts of low energy;
- Occurs in places with some tidal connection, including those rarely inundated supratidal[25] areas, intermittently closed or opened lagoons, and groundwater influences, but not those areas only subject to aerosol spray[26];
- Consist of dense to patchy areas of characteristic coastal saltmarsh plant species (that is, salt tolerant herbs, succulent herbs and shrubs and/or grasses and may include bare ground as part of the mosaic);
- Proportional tree canopy cover (of for example, mangroves or *Casuarina*/*Melaleuca*) or ground cover by seagrass is less than 50%; and
- Patch size must exceed 0.1 hectares, however, smaller patches (<0.1ha) that are within 30 metres of each other and in total exceed 0.1 hectares, are considered a saltmarsh community (underlining is my emphasis).

The Conservation Advice also notes two exclusions that have relevance within a Tasmanian context:

- Areas of saltmarsh that occur on inland saline soils that have no tidal influences; and
- Areas of (possibly senescent) saltmarsh where connection (either artificially or naturally) to the tidal regime has been severed (but was once connected to a tidal influence). However, the Advice does come with a caveat – "Coastal saltmarsh cut off from the sea by natural barriers but subject to seepage from the sea should be included in the definition" (p. 15) (my emphasis).

Additionally, the Conservation Advice comments on salt tolerant vegetation found within coastal saltmarshes where plant species specifically consist of herbs, shrubs, sedges, grasses and rushes. Species listed (in the Advice), those in a Tasmanian context,

[25] A supratidal area is that zone above the spring tide height on coastlines and estuaries that may receive intermittent marine waters from weather assisted tides such as storm surges and from the highest astronomical tides.
[26] Generally, sea cliffs and rock platforms on elevated headlands situated above the full tidal limit and subject to only wind borne (aerosolic) salt.

include *A. stipoides, G. filum, J. kraussii, S. repens, S. quinqueflora, Suaeda australis, T. arbuscula* and *Wilsonia* species *backhousei* and *rotundifolia.*

It is obvious from the Conservation Advice that several criteria, which include both floristic and physical aspects, form critical components in the definition of a coastal saltmarsh. This now needs to be applied in a Tasmanian context so that a suitable working definition can be finalised for coastal saltmarshes.

2.1.5 Defining coastal saltmarshes – TASVEG

TASVEG 3.0 is a broad-scale digital map of Tasmania's vegetation depicting over 150 vegetation communities, including alpine vegetation, eucalypt forests and coastal heathlands (Department of Primary Industries 2015). One such category is Saltmarsh and Wetland[27], which lists eight vegetation communities. Of these four, AHS: saline aquatic herbland, ARS: saline sedgeland/rushland, ASS: succulent saline herbland, and AUS: saltmarsh (undifferentiated), are classified as saltmarsh/saline, and one other identified as AWU: wetland undifferentiated (Table 2.1). As AHS relates to "…communities that occur in areas of permanent or semi-permanent brackish to hyper-saline water…" (p. 8) (my emphasis), this classification is no longer considered within this study.

Table 2.1: TASVEG 3.0 codes currently applied to saltmarsh/wetland vegetation. **Source:** Kitchener and Harris (2013). **Note:** TASVEG does not distinguish between herbfield and herbland. Both terms are used within code descriptions. Underlined text = my emphasis.

ARS = Saline sedgeland/rushland a coastal community often dominated by *J. kraussii* or, sometimes by other species such as *G. filum*. Succulent species may be intermixed. Community may be dense or have sparse sedges and rushes with smaller sedges and herbs in the inter-tussock spaces. Community height varies between 0.5-2m and are restricted to the margins of saltmarsh areas and lower reaches of estuaries often forming a zone on the landward margins of saline herbfields (p. 10).
ASS = Succulent saline herblands are low growing communities dominated by *S. quinqueflora* and in some cases *Sclerostegia arbuscula* (now known as *T. arbuscula*) the latter being a shrub up to 80 cm high. Often the community has a strong reddish tinge. They are distinguished by the dominance of one or more of the succulent coastal species. These communities occur on gently graded low energy coasts, most commonly in estuaries as well as in the lowest rainfall zone of the Midlands (p. 16).
AUS = Saltmarsh (undifferentiated) – as for ASS and ARS – this code "used where field access is not possible and remote allocation to a more specific unit is not advised" (Kitchener & Harris 2013, p. 15)
AWU = Wetland (undifferentiated) is used where separation using remote mapping methods has not been possible. This code "used where field access is not possible and remote allocation to a more specific unit is not advised" (Kitchener & Harris 2013, p. 18).

[27] Follows: Vegetation Benchmarks: v1 Saltmarsh and wetland (after Kitchener and Harris (2013)).

Here, vegetation community ARS has been classified as coastal, whereas ASS is found both inland and coastal, thus the classification of ASS has an aspect of duality when relating to the physical location of saltmarshes – coastal and inland. This needs to be treated with some care when using TASVEG as an essential characteristic in defining a Tasmanian coastal saltmarsh. Furthermore, no mention is made within the TASVEG codes of non-vegetated areas – bare ground, those that are often found within individual saltmarsh vegetation communities (personal observations).

Spray zones within TASVEG are not recognised within the Saltmarshes and Wetlands classification but fall within the Scrub, Heathland and Coastal Complexes[28] classification as SSZ: Spray zone coastal complex (Table 2.2). This listing adequately describes its position in the landscape – coastal – and connection to marine influences – extreme salt spray and inundation. Furthermore, floristics are also described as containing succulent herbfield with distribution being regulated by length of inundation.

Table 2.2: TASVEG 3.0 code currently applied to Scrub, Heathland and Coastal Complexes classification. **Source:** Kitchener and Harris (2013). Underlined text = my emphasis.

SSZ = Spray zone coastal complex occurs on steep coastal slopes and cliffs of high-energy coastlines subject to extreme salt spray and often inundation. This wind-pruned vegetation is comprised of highly salt tolerant coastal heathland and succulent herbfield. Several plant sub-communities may co-exist within a relatively small area, with their distribution relating to exposure, substrate type and length of inundation. Species diversity and density of cover increases on more protected sites. Lichens often encrust the rocks (p. 58).

The species list within this classification includes *S. repens, S. quinqueflora, A. stipoides, D. distichophylla* and *Schoenus nitens*, all species found in the Tasmanian saltmarsh environment (Prahalad 2014). It is noted that the SSZ listing includes true terrestrial plant species such as *Olearia glutinosa, Myoporum insulare* and *Lomandra longifolia,* which precludes the use of this classification solely within Saltmarsh and Wetlands category. However, in a landscape sense – coastal, often subject to inundation – does somewhat imply a sense of saltmarsh characterisation, suggesting that the classification is useful within a saltmarsh model definition.

[28] Follows: Vegetation Benchmarks v2: Scrub, heathland and coastal complexes (after Kitchener and Harris (2013)).

2.1.6 Defining a Tasmanian coastal saltmarsh.

The EPBC Act

The outcome from the above evidence and discussion of Tasmanian coastal saltmarshes, and the relationship to the Conservation Advice under the EPBC (1999) Act, where both floristics and physical aspects play an equal role, is presented in Table 2.3.

Table 2.3: Tasmanian coastal saltmarshes by Classification, Type, connectedness to the sea, tidal influence, presence of halophilic plant species and relevance to the EPBC (1999) Act.

Class	Type	Connected to the sea	Under tidal influence	Evidence of halophilic plant species	Covered by EPBC (1999) Act coastal saltmarsh criteria
Functional	Coastal estuary	Yes	Yes	Yes, very rich [1]	Yes
	Coastal embayment	Yes	Yes	Yes, very rich [1]	Yes
Semi-functional	ICOL	Yes	Yes	Yes [2]	Yes
	Perched	No	No	Yes, limited richness [3]	No
	Spray zone	Yes	Yes	Yes, limited richness [3]	Yes
Non-functional	Stranded	Currently possible via seepage, however yes in the future	No, however yes in the future	Yes, limited richness [3]	Yes/No

[1] Full range of plant species (100%) found in coastal estuaries.
[2] A full range of plant species not found (only ~ 50-75%).
[3] Initial vegetation assessments suggest that species richness is somewhat limited (~30%).

Reviewing the EPBC Act definition and diagnostic criteria, all Tasmanian coastal saltmarsh classification/types (see Figure 2.3 – flowchart, page 2.4), to the exclusion of perched marshes, would meet the key diagnostics and survey guidelines within that definition.

TASVEG

The outcome from the discussion and evidence of Tasmanian coastal saltmarshes and relationship to TASVEG is presented in Table 2.4. Here it is noted that floristics plays a dominant role while the physical aspect has a lesser function.

Table 2.4: Tasmanian coastal saltmarshes based on floristics and relevance to TASVEG.

Class	Type	Under tidal influence	Evidence of halophilic plant species	Covered TASVEG criteria
Functional	Coastal estuary	Yes	Yes, very rich [1]	Yes
	Coastal embayment	Yes	Yes, very rich [1]	Yes
Semi-functional	ICOL	Yes	Yes [2]	Yes
	Perched	No	Yes, limited richness [3]	No
	Spray zone	Yes	Yes, limited richness [3]	Yes
Non-functional	Stranded	No, however yes in the future	Yes, limited richness [3]	Not clear

[1] Full range of plant species (100%) found in coastal estuaries.
[2] A full range of plant species not found (only ~ 50-75%).
[3] Initial vegetation assessments suggest that species richness is somewhat limited (~30%).

The position of saltmarshes within TASVEG, is principally based on floristics. It is evident that most Tasmanian coastal saltmarsh classification/types (see Figure 2.3 – flowchart, page 2.4) would fit within the current guidelines, however, perched marshes fall outside the guidelines. In respect of stranded marshes, there are no clear indications within TASVEG whether this saltmarsh type would be included.

Proposed definition

The EPBC Act and TASVEG are mostly complimentary on guidelines in defining a Tasmanian coastal saltmarsh. Perched marshes should not be included, because there is no connection to the sea, and marine inundation does not occur, nor is it likely to occur. However, stranded marshes are contained within the EPBC Act, with limitations, and should be included if subject to seepage from the sea, though there is no mention within TASVEG. Floristically (containing saltmarsh plants) and the position in the landscape (being coastal), consideration within the definition should be made for stranded marshes. Furthermore, the prospect of future reconnection to the sea due to sea-level rise, which will highly likely result in tidal inundation, strengthens the case for inclusion within a definition.

It is proposed as follows:

Tasmanian coastal saltmarshes are defined as those areas that:

1) Are located within the coastal zone,

2) Floristically display halophilic plants,

3) Are currently under regular or intermittent tidal influence (including astronomical tides and storm surge), which includes lagoonal estuaries that are open intermittently, known as ICOLs (intermittently closed and open lagoons),

4) Experience episodical inundation (e.g. storm surge) and are subject to extreme aeolic salt deposits, which includes spray zones, and

5) Have been identified as locations possibly connected to the sea by way of seepage from adjoining marine waters and will be subject to inundation in the foreseeable future (~ 2100) because of sea-level rise or storm surge.

To identify coastal saltmarsh sites, areas should be assessed by the following criteria in order:

1. Be in a coastal area;
2. Floristically display halophilic plants;
3. Be currently under the influence of tides and/or storm surge whether regular or episodical; or
4. Be identified that sometime in the foreseeable future the area will come under the influence of tides or storm surge whether regular or intermittent.

The above definition is applied in the selection of sites used in this study.

2.2 Study sites

From herein –

LOCATION = general geographical location of each study site (e.g. Maria Island, King Island).

SITE = specific place within each location (e.g. Chinamans Bay on Maria Island, Sea Elephant Bay on King Island).

PLOT = specific study areas at each site.

Site selection was based on IBRA6.1 (see Chapter 1), as this terrestrial regionalisation has been designed to reflect the geographical, geological, climatic and floristic attributes that impact plant species presence/abundance. Furthermore, IBRA has been regularly updated as new knowledge and information is acquired; IBRA6.1 is the most relevant in respect of Tasmania's regional boundaries.

A review of Prahalad (2014) determined that three of the six coastal bioregions/ subregions, King (KIN), Flinders (FUR02) and Tasmanian South East (TSE), harbour the majority of Tasmania's native coastal saltmarshes. The remainder are situated in Tasmanian Southern Ranges (TSR), Tasmanian West (TWE) and Tasmanian Northern Slopes (TNS) bioregions, the latter two regions containing the least number of coastal saltmarsh sites. Throughout this project, selection of sites was based on the principles of comprehensiveness, adequate and representativeness CAR (see: http://www.environment.gov.au/land/nrs/science/scientific-framework).

CAR means:

Comprehensive: the inclusion of examples of regional-scale ecosystems in each bioregion;

Adequate: the inclusion of sufficient levels of each ecosystem to provide ecological viability and to maintain the integrity of populations, species and communities; and

Representative: the inclusion of areas at a finer scale, to encompass the variability of habitat within ecosystems (Department of the Environment 2015).

To be selected, each coastal saltmarsh site must:

- Fall within the definition of Tasmanian coastal saltmarshes (established above – see Section 2.1.6);
- Be seaward of the seawater/freshwater interface in tidal river estuaries, such as the Huon River at Huonville (Environment Division 2003); and
- Be reasonably accessible by land (this does not include Tasmanian offshore islands (e.g. Maria/Bruny Islands), accessible by regular ferry operations, or King/Flinders Island, accessible by regular air services).

As part of the site selection process, degradation (that is "human impact") was also considered as a component of representation used in CAR (see above), however, land tenure status was not used as a criterion for selection. In both cases, degradation and land tenure, a mix of sites was sought, and wherever possible sites were equitably spread within each coastal bioregion, either latitudinally, longitudinally or both.

Access to sites identified as being National Park, State Reserve, Nature Reserve, Game Reserve, Conservation Area, Nature Recreation Area, Regional Reserve, Public Reserve or Crown Land was sought from relevant governmental authorities (e.g. Department of Primary Industries, Parks, Water and Environment), and access to sites identified as Private Freehold, Private Sanctuary, Private Nature Reserve or Conservation Covenant and was sought from relevant lease/landowners. All sites are situated in native coastal saltmarshes, those locations infested by *Spartina anglica* (locally known as rice grass), a vigorous and invasive introduced species, were excluded from this study.

To achieve the aims outlined in Chapter 1, this study was carried out in three phases:

• Phase 1 – formulate a draft saltmarsh vegetation community key using Training sites (those listed in the Appendix of this Chapter) on a state-wide basis;

• Phase 2 – apply the draft key at a selection of Test 1 sites (listed in Appendix), principally those located in regions most populated by coastal saltmarshes; prepare an updated and improved proposed saltmarsh vegetation community key;

and

• Phase 3 – apply the proposed key to a range of Test 2 sites (listed in Appendix), ideally located state-wide; aggregate the data from Training, Test 1 and Test 2 sites to create a Combined dataset and prepare a final vegetation community key that will be applicable and useful on a state-wide basis.

Additionally, soil samples were collected from all plots during each individual phase, and the collective laboratory analysis data used in Chapters 4, 5 and 6.

2.2.1 Phase 1 – Training sites

Site selection for Phase 1 (to propose a draft vegetation community key) was based on IBRA6.1. Training sites were situated state-wide around the Tasmanian mainland coast with one site located on each of the four major off-shore islands (King, Flinders, Maria and Bruny islands). Informally, site selection was random, however two bioregions had a limited number of coastal saltmarshes that didn't permit a randomised selection. Selection of Training sites (n = 21, comprising 110 plots) was based on current classification by TASVEG 3.0, a fit within the definition (detailed above) and accessibility to individual sites. No consideration was given to type of land tenure and

degradation due to human influences because it was felt important to capture as much diversity within these features as possible. A minimum of three sites were selected from each IBRA bioregion and spread along the bioregion's coastline wherever possible. However, saltmarshes in the TWE bioregion were restricted to Macquarie Harbour because (at that time) it was the only known location of saltmarshes in this region, and the TNS bioregion had only two coastal saltmarsh sites that were suitable for assessment.

Training sites are presented in Appendix 2A.1 and Figures 2.36 to 2.39 (each individual Training site is marked in **red** on maps).

2.2.2 Phase 2 – Test 1 sites

Selection of Phase 2 (test and update the draft vegetation community key) Test 1 sites were predominately from IBRA6.1 bioregions that contained a greater occurrence of saltmarshes – northeast, east and far northwest sections (Prahalad 2014) – yet still with the aim to capture as much diversity of vegetation community type found in all coastal IBRA bioregions. Furthermore, additional sites were also established on the major off-shore islands, Flinders, Maria, Bruny and King, these representing three of the six coastal IBRA bioregions. Test 1 sites (n = 27, comprising 128 plots) were selected at random, subject to ease of accessibility, with an objective of distribution along the coastline. Approval from a private land owner to one selected site at Georges Bay (St Helens) was refused, however another site was chosen in that vicinity.

Test 1 study sites are presented in Appendix 2A.2 and Figures 2.36 to 2.39 (each individual site marked in **green** on maps).

2.2.3 Phase 3 – Test 2 sites

Selection of Phase 3 (final test of proposed vegetation community key) Test 2 sites (n = 43, comprising 169 plots) was more circumspect, in that several sites chosen were not recognized within TASVEG, but based on the above definition. Intensive ground truthing on Tasmania's west coast identified several locations that fitted within the definition of coastal saltmarshes, with several being incorporated in the assessments. The remaining sites included intermittent closed and open lagoons (ICOLs), spray zones and stranded marshes. These were selected to fill several obvious gaps within the

definition. IBRA6.1 regionality was still used as a basis of site location. Several sites were difficult to access and entailed wading across fast running tidal flows, the use of boats and four wheel drive vehicles, and extended walks. Tasmania's south and south west coasts (between Macquarie Harbour and South East Cape) are extremely remote and generally inaccessible except by boat, helicopter, or by bushwalking, which can entail periods of up to two weeks often in dubious terrain. General access to the area is by light fixed wing aircraft to Melaleuca Airstrip, then by vessel within Port Davey and Bathurst Harbour, this only being accomplished during periods of stable, fine weather. The coastline is subject to strong north-westerly to south-westerly weather extremes (BOM 2018b), which in many instances precludes the existence of coastal saltmarshes. Extensive desktop research using high resolution aerial images identified possible areas of interest, particularly, Paynes Bay and Hannant Inlet, both areas accessible from within Port Davey. Access to the two areas was possible during early April 2018, allowing the sites to be ground truthed, however, time spent in the area was limited to just one day.

Test 2 study sites are presented in Appendix 2A.3 and Figures 2.36 to 2.39 (each individual site marked in **blue** on maps).

2.2.4 Sites & Status

Each site was designated a two or three letter code identifying site name, for example, Dorans Road = DR, or Sea Elephant Bay = SEB, and with a two letter suffix identifying the land tenure status of each individual Training, Test 1 and Test 2 site (Appendix 2A.4 to 2A.6).

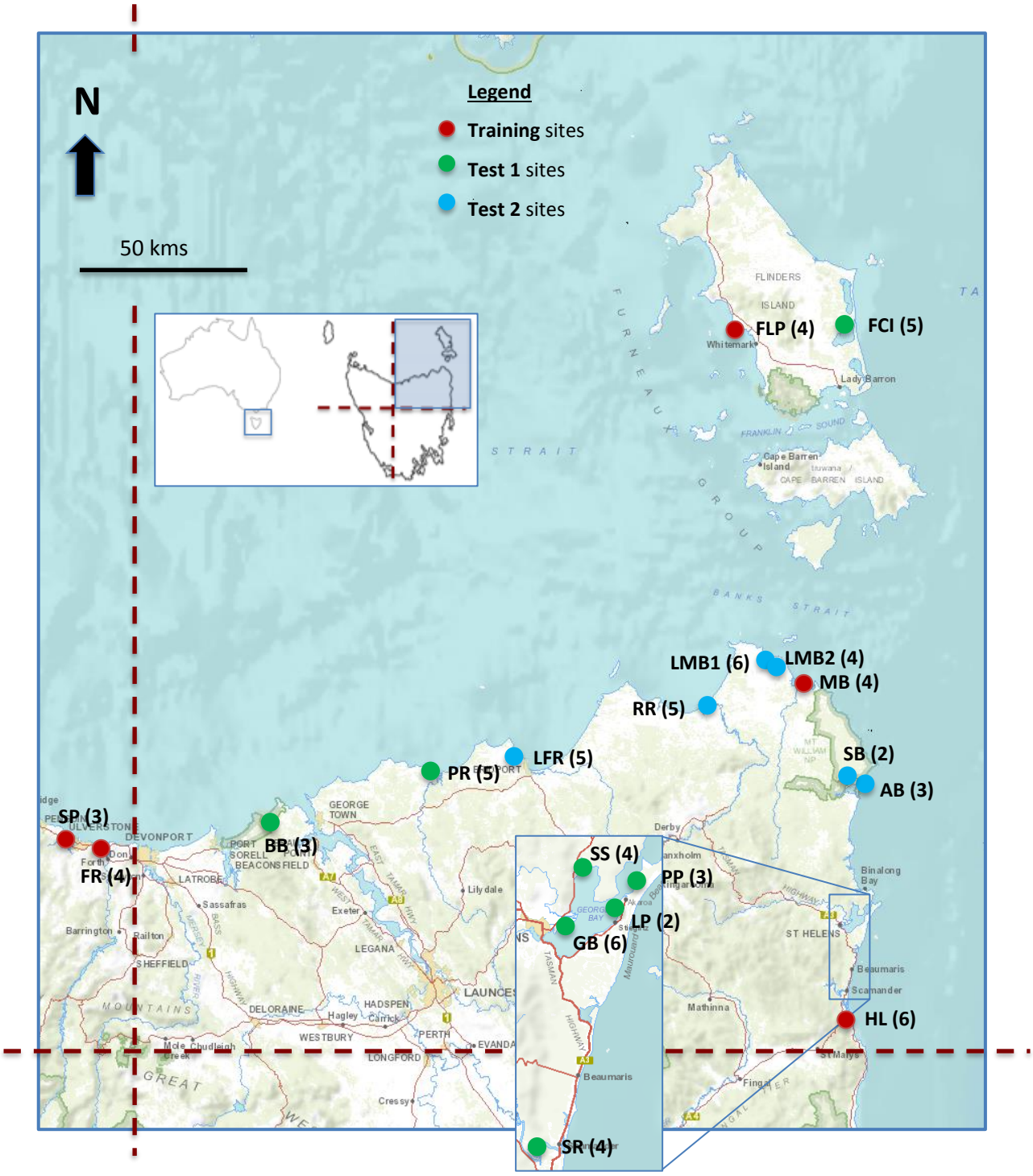


Figure 2.36: Locations of **Training, Test 1** and **Test 2** sites in north east Tasmania including the Furneaux Group (includes Flinders Island). **Map insert:** Georges Bay to Scamander region. **Source:** DPIPWE (2018a).

Site codes: AB = Ansons Bay; **BB** = Bakers Beach; **FCI** = Flinders Cameron Inlet; **FLP** = Flinders Long Point; **FR** = Forth River; **GB** = Georges Bay; **HL** = Hendersons Lagoon; **LFR** = Little Forester River; **LMB1** = Little Musselroe Bay 1; **LMB2** = Little Musselroe Bay 2; **LP** = Lords Point; **MB** = Musselroe Bay; **PP** = Pelican Point; **PR** = Pipers River; **RR** = Ringarooma River; **SB** = Shark Bay (Ansons Bay); **SP** = Singletons Point; **SR** = Scamnander River; **SS** = Sams Spit.

The numeric suffix to each code (in parenthesis) indicates the number of plots at that site.

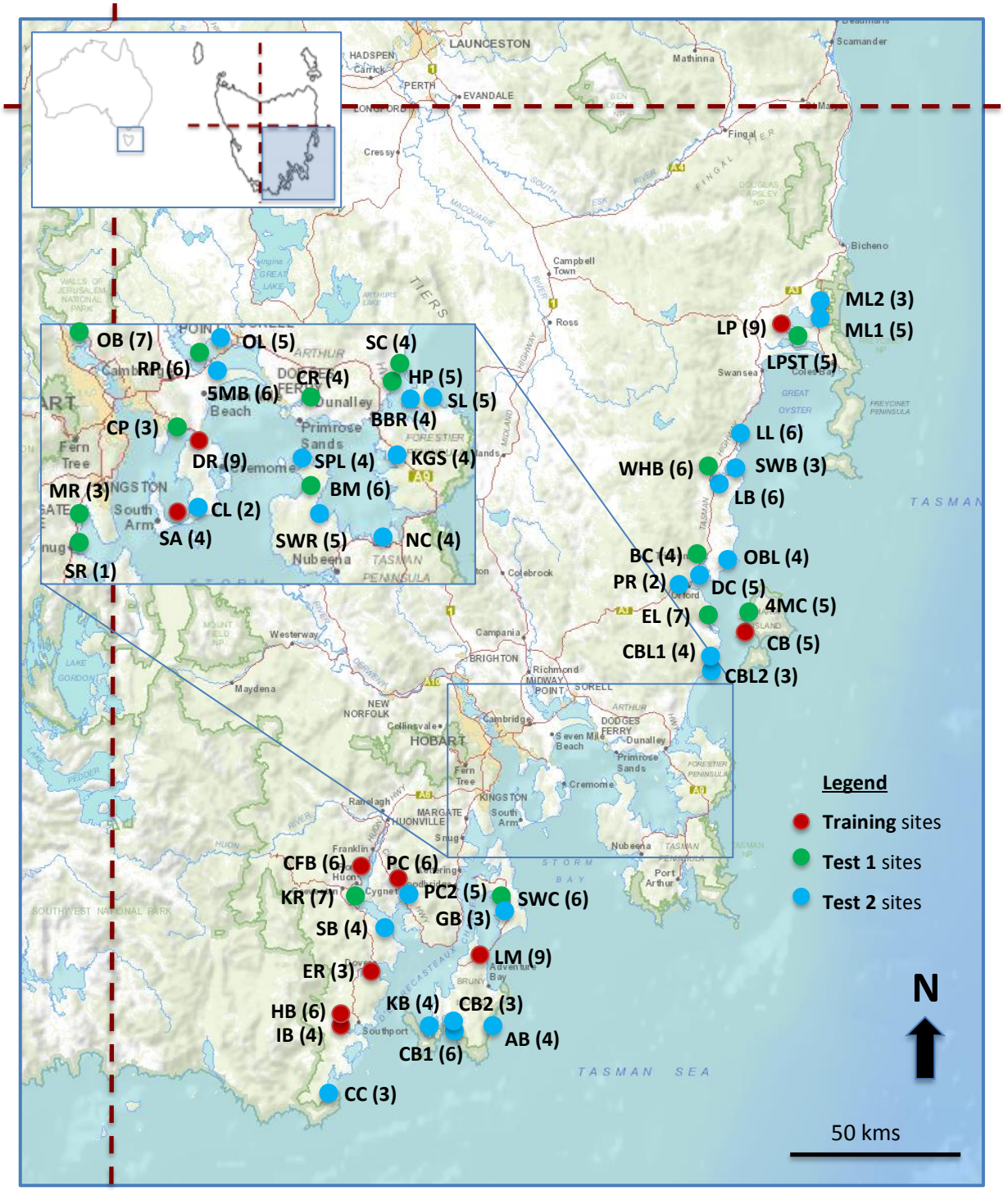


Figure 2.37: Locations of **Training, Test 1** and **Test 2** sites in south east Tasmania including Maria and Bruny Islands. **Map insert:** South east inshore region. **Source:** DPIPWE (2018a).

Site codes are listed on following page.

Site codes: 4MC = 4 Mile Creek; **5MB** = 5 Mile Beach; **AB** = Adventure Bay; **BBR** = Blackman Bay Rivulet; **BC** = Bresnehans Creek; **BM** = Burdons Marsh; **CB** = Chinamans Bay; **CB1** = Cloudy Bay 1; **CB2** = Cloudy Bay 2; **CBL1** = Cockle Bay Lagoon 1; **CBL2** = Cockle Bay Lagoon 2; **CC** = Cockle Creek; **CFB** = Castle Forbes Bay; **CL** = Calverts Lagoon; **CP** = Clarence Plains; **CR** = Carlton River; **DC** = Double Creek; **DR** = Dorans Road; **EL** = Earlham Lagoon; **ER** = Esperance River; **GB** = Great Bay; **HB** = Hastings Bay; **HP** = Hildyards Point; **IB** = Ida Bay; **KB** = Kingfisher Beach; **KGS** = King George Sound; **KR** = Kermandie River; **LB** = Luttrells Bay; **LL** = Lisdillon Lagoon; **LM** = Lutregala Marsh; **LP** = Long Point; **LPST** = Long Point (salinity trial); **ML1** = Moulting Lagoon; **ML2** = Moulting Lagoon 2; **MR** = Margate River; **NC** = Newmans Creek; **OB** = Old Beach; **OBL** = Okehampton Beach Lagoon; **OL** = Orielton Lagoon; **PC** = Port Cygnet; **PC2** = Port Cygnet; **PR** = Prosser River; **RP** = Railway Point; **SA** = South Arm; **SB** = Surges Bay; **SC** = Sedbury Creek; **SL** = Swan Lagoon; **SPL** = Sloping Lagoon; **SR** = Snug Rivulet; **SWB** = Sheepwash Bay; **SWC** = Saltwater Creek; **SWR** = Saltwater River; **WHB** = Watch House Bay.

The suffix value to each code (in parenthesis) indicates the number of plots at that site.

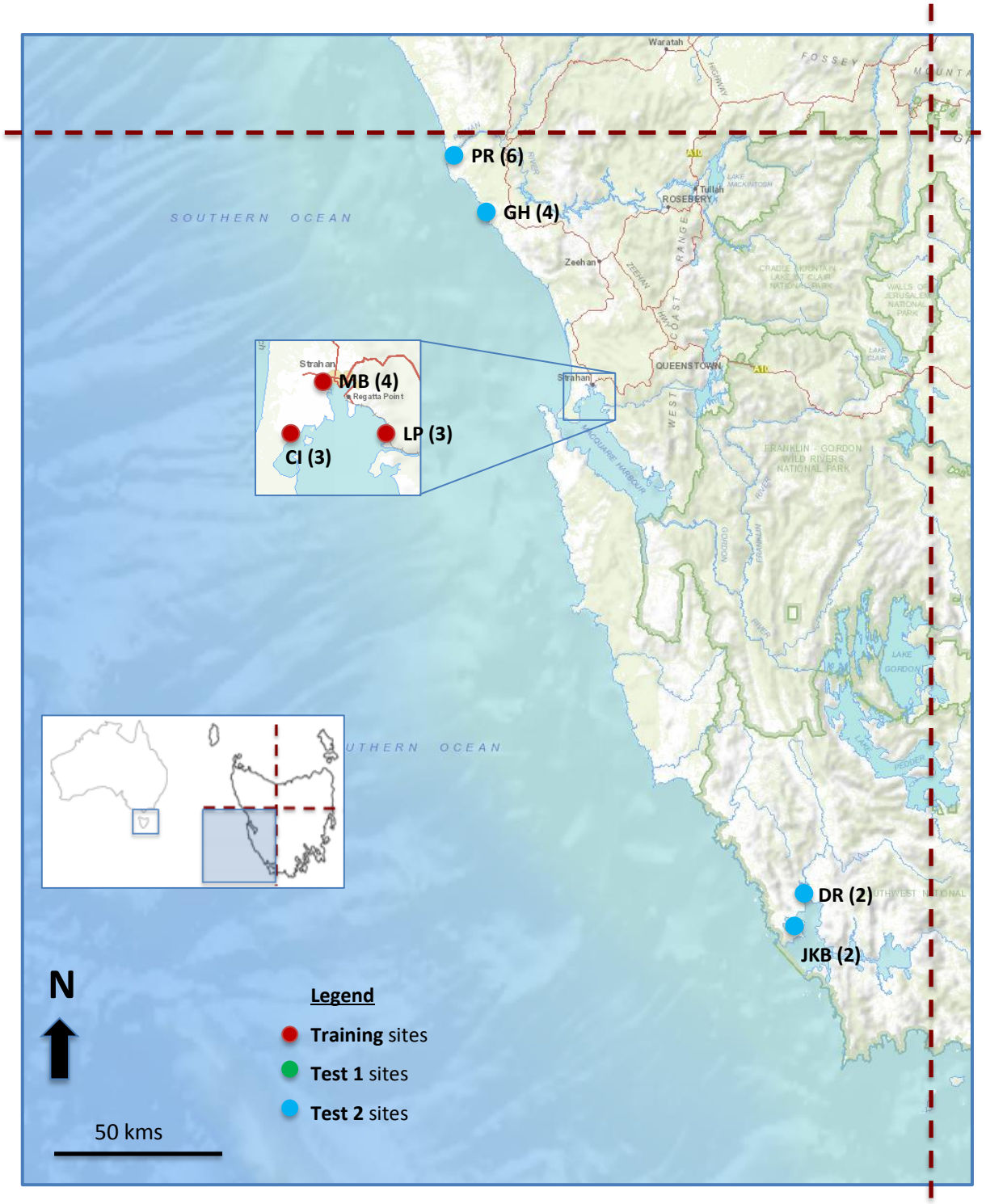


Figure 2.38: Locations of **Training, Test 1** and **Test 2** sites in south west Tasmania. **Map insert:** northern portion of Macquarie Harbour. **Source:** DPIPWE (2018a).

Site codes: CI = Cat Island; **DR** = Davey River; **GH** = Granville Harbour; **JKB** = James Kelly Basin; **LP** = Lowana Point; **MB** = Mill Bay; **PR** = Pieman River.

The suffix value to each code (in parenthesis) indicates the number of plots at that site.

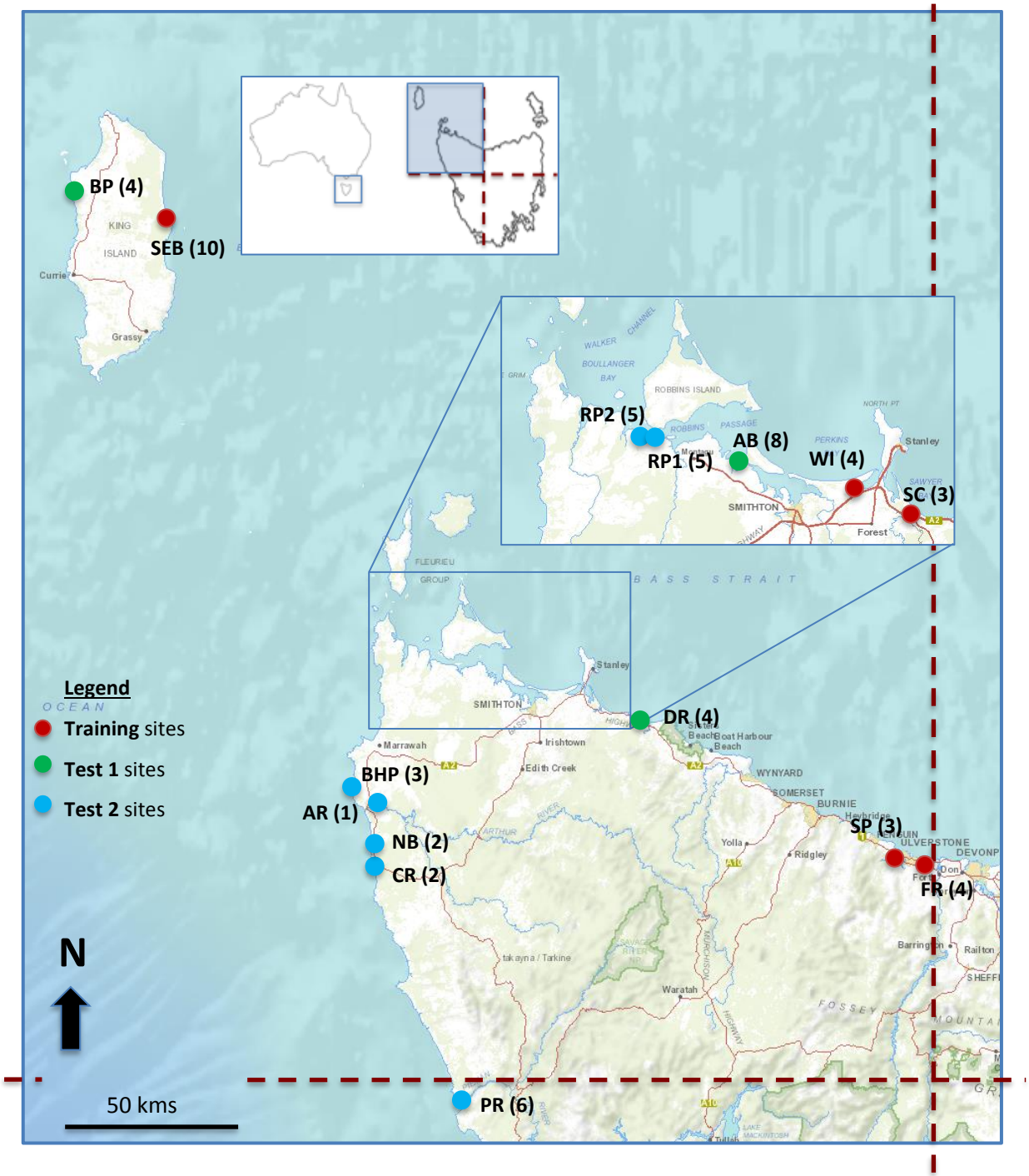


Figure 2.39: Locations of **Training, Test 1** and **Test 2** sites in north west Tasmanian including King Is and the Fleurieu Group. **Map insert:** Far northwest (Circular Head) region. **Source:** DPIPWE (2018a).

Site codes: AB = Acton Bay; **AR** = Arthur River; **BHP** = Bluff Hill Point; **BP** = Bungaree Point; **CR** = Couta Rocks; **DR** = Detention River; **FR** = Forth River; **NB** = Nelson Bay; **PR** = Pieman River; **RP1** = Robbins Passage 1; **RP2** = Robbins Passage 2; **SC** = Snake Creek; **SEB** = Sea Elephant Bay; **SP** = Singletons Point; **WI** = West Inlet.

The suffix value to each code (in parenthesis) indicates the number of plots at that site.

2.3 Acknowledgements

The scale of this project would have been very limited and could not have been achieved without the generosity of many land owners who either granted permission to carry out sampling in saltmarshes on their land or allowed access through their property to prospective sites along the coast. In particular, many thanks go to Peter Boulot, Mark Dunbabin, Matt Dunbabin, John Gray, Margaret Ollington, John Price, David Probert, John Salmon, Jean Weeding, the Tasmanian Land Conservancy, Huon Aquaculture and the Tasmanian Aboriginal Council. Special appreciation to Pieter van de Woude from Tasmanian Boat Charters who arranged available seating on a charter flight to Melaleuca Inlet and also provided water transport to sites in Port Davey. Additionally, much gratitude goes to the Department of Primary Industries, Parks, Water and Environment for access to coastal National Parks and Reserves in which many saltmarshes are found. Finally, many thanks to Vishnu Prahalad for desktop and field assistance in the never-ending search for suitable study sites (which at times included robust discussions) and the use of several photos.

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2.5 Appendices

2A.1 Training site details

2A.2 Test 1 site details

2A.3 Test 2 site details

2A.4 Training sites land tenure

2A.5 Test 1 sites land tenure

2A.6 Test 2 sites land tenure

2A.1: Training sites details

Table 2A.1: Coastal saltmarsh vegetation assessment Training sites (clockwise IBRA6.1 bioregion Furneaux through to bioregion Tasmanian Northern Slopes).

IBRA bioregion	Training site/ Location	Area (ha)	Latitude/ Longitude	TASVEG code *	Scale of impact ** (reason/cause)
Furneaux	Long Point (Flinders Is)	17.32	40.07461S; 147.96118E	ASS, ARS	1 (adjacent to grazing land)
	Musselroe Bay (Musselroe Bay)	8.81	40.83653S; 148.14607E	AWU	4 (vehicular damage)
	Hendersons Lagoon (Falmouth)	5.93	41.48589S; 148.26007E	AWU	2 (public access)
Tasmanian South East	Long Point (Moulting Lagoon)	303.60	42.05114S; 148.15096E	ASS, ARS	3 (prior to 2005 sheep grazing)
	Chinamans Bay (Maria Island)	5.80	42.65449S; 148.04025E	ASS, AUS	1 (National Park)
	Dorans Road (Lauderdale)	10.72	42.92926S; 147.48867E	ASS	2 (old drainage and fencing)
	South Arm (Ralphs Bay/Neck)	11.30	43.03198S; 147.44513E	AUS	2 (some grazing – now recovered)
	Port Cygnet (vicinity Lymington Road)	4.35	43.16782S; 147.08092E	ARS	3 (public access tracks)
Tasmanian Southern Ranges	Lutregala Marsh (Bruny Island)	47.95	43.29662S; 147.30806E	ASS	2 (old drainage and fencing)
	Castle Forbes Bay (Castle Forbes Bay)	4.32	43.13224S; 146.98115E	ARS	2 (drainage creek modified)
	Hastings Bay (Hastings Bay)	10.07	43.41571S; 146.92057E	ARS	1 (adjacent to bushland buffer)
	Ida Bay (Ida Bay)	2.04	43.44638S; 146.91671E	AUS	1 (adjacent to bushland buffer)
Tasmanian West	Lowana Point (mouth of King River)	8.33	42.18785S; 145.36069E	AUS	4 (sedimentation from King River)
	Cat Island (off Macquarie Heads Rd)	4.88	42.18525S; 145.28514E	AUS	1 (pristine –small island)
	Mill Bay (Strahan)	1.76	42.15152S; 145.31159E	AUS	4 (adjacent to town)
King	Sea Elephant Bay (King Island)	21.84	39.81395S; 144.10685E	ASS	1 (State Reserve - intact)
	West Inlet (Stanley)	26.19	40.81158S; 145.21557E	ARS	3 (some grazing, sedimentation)
	Snake Creek (Black River)	14.64	40.85041S; 145.32107E	ARS	2 (access from adjacent camp grounds)
Tasmanian Northern Slopes	Singletons Pt (Leven River)	5.00	41.15715S; 146.12914E	ASS	2 (adjacent to grazing land – sedimentation)
	Forth River (off Bass Highway)	4.73	41.16737S; 146.24625E	AWU	2 (adjacent to grazing land – sedimentation)

***** See **Table 2.1** (page 2.19 above) for explanation.

****** Scale of impact: 1 = nil (impact) ----------> 5 = totally modified.

2A.2: Test 1 sites details

Table 2A.2: Coastal saltmarsh vegetation assessment Test 1 sites (clockwise IBRA6.1 bioregion Furneaux through to bioregion Tasmanian Northern Slopes).

IBRA bioregion	Test 1 site/ Location	Area (ha)	Latitude/ Longitude	TASVEG code *	Scale of impact ** (reason/cause)
Furneaux	Sams Spit (Moulting Bay)	7.52	41.28452S; 148.27886E	AUS	3 (public access)
	St Helens (Georges Bay)	2.81	41.32373S; 148.25500E	AUS	3 (public access)
	Scamander River (Upper Scamander)	18.63	41.46725S; 148.24543E	AWU	2 (public access)
	Pelican Point (Georges Bay)	9.23	41.28928S; 148.32961E	AUS	2 (public access)
	Lords Point (Georges Bay)	1.84	41.30125S; 148.31974E	ASS	3 (public access)
	Cameron Inlet (Flinders Island)	2.86	40.07099S; 148.28512E	Nil	3 (public access)
	Pipers River (Pipers River)	1.18	41.02009S; 147.15859E	AWU	3 (public access)
	Bakers Beach (Narawntapu NP)	85.77	41.15513S; 146.59103E	ASS	2 (public access)
Tasmanian South East	Long Point (Moulting Lagoon)	6.95	42.05587S; 148.14711E	ASS	3 (prior to 2005 used for sheep grazing)
	Snug River (Snug)	0.32	43.16204S; 147.25720E	ARS	3 (public access)
	Margate Rivulet (Margate)	7.54	43.02545S; 147.26735E	ASS	4 (grazing, some fencing)
	Sedbury Creek (Marion Bay)	1.14	42.81951S; 147.86312E	ARS, ASS	2 (public access)
	Carlton River (Carlton River)	22.12	42.87806S; 147.66031E	ASS	3 (public access)
	Bresnehans Creek (Triabunna)	3.68	42.50186S; 147.92112E	ASS, AUS	3 (public access)
	Clarence Plains Rivulet (Rokeby)	2.98	42.90763S; 147.43292E	ASS	4 (grazing)
	Hildyards Point (Blackman Bay)	5.15	42.85869S; 147.84185E	ASS	2 (public access)
	Watch House Bay (Little Swanport)	28.68	42.33987S; 147.93528E	ASS	2 (public access)
	Saltwater Creek (north Bruny Island)	2.70	43.17695S; 147.37975E	ARS	3 (some grazing)
	Earlham Lagoon (Rheban)	170.8	42.63991S; 147.93233E	AUS, ARS	3 (some grazing, old fences)
	Burdons Marsh (Tasman Peninsula)	88.27	42.98709S; 147.68768E	ASS	3 (grazing, old fences, convict era drains)
	Old Beach (Old Beach)	4.61	42.78177S; 147.27064E	AUS	3 (public access, tracks)
	Railway Point (upper Pitt Water)	17.49	42.81266S; 147.48483E	ASS	1 (conservation area)

IBRA bioregion	Test 1 site/ Location	Area (ha)	Latitude/ Longitude	TASVEG code *	Scale of impact ** (reason/cause)
Tasmanian South East (cont'd)	4 Mile Creek (Maria Island)	5.50	42.62030S; 148.03949E	SHW	1 (national park)
Tasmanian Southern Ranges	Kermandie River (Strathblane)	18.03	43.15905S; 146.95661E	ARS	2 (public access, drains, fencing)
King	Acton Bay (Montagu)	34.72	40.78479S; 145.03735E	ASS, AUS	4 (grazing)
	Detention River (Detention)	1.50	40.87578S; 145.44313E	AWU	3 (public access)
	Bungaree Point (King Island)	0.75	39.77118S; 143.85098E	Nil	2 (public access)

***** See **Table 2.1**, page 2.19 (above) for explanation; additional codes **– SHW** = wet heathland, **Nil** = unclassified vegetation community within TASVEG 3.0.
****** Scale of impact: 1 = nil (impact) ----------> 5 = totally modified.

2A.3: Test 2 sites details

Table 2A.3: Coastal saltmarsh vegetation assessment Test 2 sites (clockwise IBRA6.1 bioregion Furneaux through to bioregion Tasmanian Northern Slopes).

IBRA bioregion	Test 2 site/ Location	Area (ha)	Latitude/ Longitude	TASVEG code *	Scale of impact ** (reason/cause)
Furneaux	Ringarooma River (Boobyalla)	25.08	40.87539S; 147.89107E	ASS	1 (inaccessible)
	Little Forester River (Bridport)	18.24	40.97074S; 147.35972E	Nil	2 (limited access)
	Little Musselroe Bay 1 (Cape Portland)	5.03	40.77185S; 148.03769E	Nil	1 (inaccessible)
	Little Musselroe Bay 2 (Cape Portland)	11.88	40.77063S; 148.04344E	Nil	1 (inaccessible)
	Ansons Bay (Ansons Bay)	3.57	41.03165S; 148.29338E	ASF	2 (limited access)
	Shark Bay (Ansons Bay)	1.18	41.03096S; 148.29171E	AWU	4 (vehicle access)
Tasmanian South East	Sloping Lagoon (Lime Bay)	13.55	42.95522S; 147.69350E	ASS	3 (vehicular access, slowly recovering)
	Saltwater River (Tasman Peninsula)	2.56	43.02508S; 147.72608E	ASS	2 (fencing, possible past grazing)
	Newmans Creek (Tasman Peninsula)	2.88	43.06110S; 147.83771E	ARS	1 (inaccessible)
	Moulting Lagoon 1 (off Coles Bay Road)	39.21	42.02361S; 148.22477E	ASS	3 (accessible from adjacent camp ground)
	Moulting Lagoon 2 (off Coles Bay Road)	33.15	41.99850S; 148.24579E	ASS	1 (limited access)
	Luttrells Bay (Little Swanport)	13.06	42.35443S; 147.96086E	ASS	2 (limited public access)
	Sheepwash Bay (Little Swanport)	0.46	42.33699S; 147.98335E	AUS	4 (accessible by stock)
	Orielton Lagoon (Sorell)	30.88	42.77839S; 147.53398E	ASS	3 (accessible, partly drained)
	Okehampton Beach (Triabunna)	6.62	42.51471S; 147.97925E	AUS	5 (stock access)
	Double Creek (Triabunna)	0.35	42.52437S; 147.89949E	FAG/FUR	2 (accessible, though on Private Freehold)
	5 Mile Beach (Llanherne)	11.47	42.82957S; 147.52171E	ASS	3 (accessible, partly cleared, recovering)
	Port Cygnet (Cygnet)	2.39	43.16872S; 147.09350E	ARS	1 (inaccessible)
	Lisdillon Lagoon (Little Swanport)	11.32	42.27678S; 148.00565E	AUS	3 (limited water ingress, installed levee)
	King George Sound (Murdunna)	0.10	42.93601S; 147.85782E	Nil	2 (limited access)
	Calverts Lagoon (South Arm Rd)	1.13	43.02093S; 147.49756E	ASS	3 (accessible to horse traffic)
	Prosser River (Orford)	0.35	42.55870S; 147.85676E	DPU	2 (limited access)

IBRA bioregion	Test 2 site/ Location	Area (ha)	Latitude/ Longitude	TASVEG code *	Scale of impact ** (reason/cause)
Tasmanian South East (cont'd)	Cockle Bay Lagoon 1 (Hellfire Bluff)	1.82	42.70733S; 147.94166E	ARS	3 (inaccessible, though past sheep access)
	Cockle Bay Lagoon 2 (Hellfire Bluff)	0.98	42.71182S; 147.93784E	ARS	4 (past modification, now recovering)
	Blackman Rivulet (Bangor)	2.49	42.89980S; 147.90177E	ASS	1 (inaccessible)
	Swan Lagoon (Bangor)	11.13	42.88121S; 147.93478E	AHL	1 (inaccessible)
	Adventure Bay (south Bruny Island)	1.95	43.36304S; 147.32752E	ASS	2 (limited access)
	Cloudy Bay 1 (south Bruny Island)	4.6	43.42297S; 147.24443E	AUS	2 (limited access)
	Cloudy Bay 2 (south Bruny Island)	2.89	43.42043S; 147.24376E	AUS	1 (inaccessible)
	Kingfisher Beach (south Bruny Island)	1.78	43.46442S; 147.16408E	AUS	1 (inaccessible)
	Great Bay (south Bruny Island)	2.71	43.21645S; 147.37399E	FAG	5 (trashed, grazing)
Tasmanian Southern Ranges	Cockle Creek (Cockle Creek)	1.17	43.58391S; 146.88436E	WOB	1 (inaccessible, old tramway, recovering)
	Surges Bay (Surges Bay)	0.72	43.21548S; 146.99187E	ARS	2 (inaccessible, marine borne rubbish)
Tasmanian West	Granville Harbour (Zeehan)	0.84	41.80626S; 145.03350E	GHC	3 (accessible)
	Pieman River (Pieman mouth)	0.39	41.66052S; 144.93190E	Nil	3 (accessible)
	Davey River (Port Davey)	1.51	43.20627S; 145.91902E	MBW	5 (inaccessible)
	James Kelly Basin (Port Davey)	0.22	43.27033S; 145.90901E	GHC	5 (inaccessible)
King	Arthur River (Arthur River)	0.03	41.04947S; 144.66994E	Nil	3 (accessible – boat ramp)
	Couta Rocks (Couta Rocks)	0.02	41.17127S; 144.67821E	SCH	2 (limited access)
	Nelson Bay (Nelson Bay)	0.02	41.12191S; 144.66769E	SCH	2 (limited access)
	Bluff Hill Point (Bluff Hill Point)	0.03	41.00991S; 144.61213E	SCH	2 (limited access)
	Robbins Passage 1 (West Montagu)	5.98	40.74944S; 144.88403E	ARS	3 (installed levee bank, now breached)
	Robbins Passage 2 (West Montagu)	3.10	40.74678S; 144.87138E	ARS	1 (inaccessible)

***** See **Table 2.1**, page 2.19 (above) for explanation; additional codes – **ASF** = fresh water aquatic sedgeland and rushland; **FAG** = agricultural land; **FUR** = urban areas; **DPU** = *Eucalyptus pulchella* forest and woodland; **AHL** = lacustrine herbland; **WOB** = *Eucalyptus obliqua* forest with broadleaf shrubs; **GHC** = coastal grass and herbfield; **SCH** = coastal heathland; **MBW** = Western buttongrass moorland; **Nil** = unclassified vegetation community in TASVEG 3.0.

****** Scale of impact: 1 = nil (impact) ----------> 5 = totally modified.

2A.4: Training sites land tenure

Table 2A.4: Tasmanian coastal IBRA6.1 bioregions, location of Training sites, tenure, associated site code and number, and number of plots.

IBRA Bioregion	Location	Site	Tenure	Site Code	Site No.	No. Plots
Furneaux	Flinders Island	Long Point	Conservation Area	FLPCA	1	4
	NE Tasmania	Musselroe Bay	Conservation Area	MBCA	2	4
	Falmouth	Hendersons Lagoon	Conservation Area	HLCA	3	6
Tasmanian South East	Moulting Lagoon	Long Point	Conservation Covenant	LPCC	4	9
	Maria Island	Chinamans Bay	National Park	CBNP	5	6
	Lauderdale	Dorans Road	Local Government	DRLG	6	9
	South Arm	The Neck	Conservation Area	SACA	7	4
	Cygnet	Port Cygnet	Conservation Area	PCCA	8	7
Tasmanian Southern Ranges	Bruny Island	Lutregala Marsh	Conservation Covenant	LMCC	9	10
	Castle Forbes Bay	Castle Forbes Bay	Unidentified (Crown Land)	CFBCL	10	6
	Strathblane	Esperance River	Crown Land	ERCL	11	3
	Hastings	Hastings Bay	Conservation Area	HBCA	12	6
	Ida Bay	Ida Bay	State Reserve	IBSR	13	4
Tasmanian West	Macquarie Harbour	Lowana Point	Public Reserve	LPPR	14	3
		Cat Island	Conservation Area	CICA	15	4
	Strahan	Mill Bay	Public Reserve	MBPR	16	4
King	King Island	Sea Elephant Bay	State Reserve	SEBSR	17	10
	Stanley	West Inlet	Private Freehold	WIPF	18	4
	Black River	Snake Creek	Conservation Area	SCCA	19	2
Tasmanian Northern Slopes	Ulverstone (Leven River)	Singletons Point	Public Reserve	SPPR	20	2
	Leith (Forth R)	Forth River	Public Reserve	FRPR	21	3

2A.5: Test 1 sites land tenure

Table 2A.5: Tasmanian coastal IBRA6.1 bioregions, location of Test 1 sites, tenure, associated site code and number, and number of plots.

IBRA Bioregion	Location	Site	Land tenure	Site code	Site No.	No. Plots
Furneaux	Georges Bay	Sams Spit	Public Reserve	SSPR	22	4
		off Quail Street	Public Reserve	GBPR	23	6
	Upper Scamander	Scamander River	Crown Land	SRCL	24	4
	Georges Bay	Pelican Point	Conservation Area	PPCA	28	3
		Lords Point	Conservation Area	LPCA	29	2
	Flinders Island	Camerons Inlet	Conservation Area	FCICA	42	5
	Bellingham	Pipers River	Crown Land	PRCL	45	5
	Narawntapu National Park	Bakers Beach	National Park	BBNP	46	3
Tasmanian South East	Moulting Lagoon	Long Point	Conservation Covenant		25	5
	Snug	Snug River	Public Reserve	SRPR	26	1
	Margate	Margate Rivulet	Private freehold	MRPF	27	3
	Marion Bay	Sedbury Creek (South)	Public Reserve	SCPR	30	4
	Primrose Sands	Carlton River	Public Reserve	CRPR	31	4
	Triabunna	Bresnehans Ck	Crown Land	BCCL	32	4
	Rokeby	Clarence Plains Rivulet	Private freehold	CPPF	33	3
	Boomer Bay	Hildyards Point	Public Reserve	HPPR	34	5
	Little Swanport	Watch House Bay	Conservation Area	WHBCA	35	6
	Bruny Island	Saltwater Creek	Private freehold	SCPF	36	6
	Rheban	Earlham Lagoon	Private Sanctuary	ELPS	37	7
	Sloping Main	Burdons Marsh	Private Freehold	BMPF	38	6
	Derwent River	Old Beach	Public Reserve	OBPR	40	7
	Cambridge	Railway Point	Conservation Covenant	RPCC	41	6
	Maria Island	4 Mile Creek	National Park	4MCNP	44	5
Tasmanian Southern Ranges	Port Huon	Kermandie River	Public Reserve	KRPR	39	7
King	Circular Head	Acton Bay	Public Reserve	ABPR	43	8
	Hellyer	Detention River	Conservation Area	DRCA	47	5
	King Island	Bungaree Point	Public Reserve	BPPR	48	4

2A.6: Test 2 sites land tenure

Table 2A.6: Tasmanian coastal IBRA6.1 bioregions, location of Test 2 sites, tenure, associated site code and number and number of plots.

IBRA Bioregion	Location	Site	Tenure	Site Code	Site No.	No. Plots
Furneaux	Boobyalla	Ringarooma River	Conservation Area	RRCA	65	5
	Bridport	Little Forester River	Conservation Area	LFRCA	66	5
	Cape Portland	Little Musselroe Bay 1	Conservation Area	LMB1CA	67	6
		Little Musselroe Bay 2	Conservation Area	LMB2CA	68	4
	Ansons Bay	Ansons Bay	National Park	ABNP	69	3
		Shark Bay	Conservation Area	SBCA	70	2
Tasmanian South East	Lime Bay	Sloping Lagoon	Conservation Area	SLCA	49	4
	Tasman Peninsula	Saltwater River	Conservation Area	SRCA	50	5
		Newmans Creek	Public Reserve	NCPR	51	4
	Moulting Lagoon	Moulting Lagoon 1	Game Reserve	ML1GR	52	5
		Moulting Lagoon 2	Game Reserve	ML2GR	53	3
	Little Swanport	Luttrells Bay	Conservation Area	LBCA	54	6
		Sheepwash Bay	Conservation Area	SBCA	55	3
	Sorell	Orielton Lagoon	Nature Reserve	OLNR	56	5
	Triabunna	Okehampton Beach Lagoon	Private Freehold	OLPF	63	4
		Double Creek	Private Freehold	DCPF	64	5
	Llanherne	5 Mile Beach	Private Freehold	5MBPF	71	6
	Cygnet	Port Cygnet 2	Conservation Area	PC2CA	73	5
	East Coast	Lisdillon Lagoon	Private Freehold	LLPF	74	6
	Murdunna	King George Sound	Conservation Area	KGSCA	75	4
	South Arm	Calverts Lagoon	Conservation Area	CLCA	76	2
	Orford	Prosser River	Private Freehold	PRPF	77	2
	Rheban	Cockle Bay Lagoon 1	Private Freehold	CBL1PF	78	4
		Cockle Bay Lagoon 2	Private Freehold	CBL2PF	79	3
	Dunalley	Blackman Rivulet	Private Freehold	BBRPF	80	4
		Swan Lagoon	Private Freehold	SLPF	81	5
Tasmanian Southern Ranges	Bruny Island	Adventure Bay	Public Reserve	ABPR	58	4
		Cloudy Bay 1	Private Freehold	CB1PF	59	6
		Cloudy Bay 2	Public Reserve	CB2PR	60	3
		Kingfisher Beach	National Park	KBNP	61	4
		Great Bay	Conservation Area	GBCA	62	3

IBRA Bioregion	Location	Site	Tenure	Site Code	Site No.	No. Plots
Tasmanian Southern Ranges (cont'd)	Cockle Creek	Cockle Creek	National park	CCNP	57	3
	Surges Bay	Surges Bay	Public Reserve	SBPR	72	4
Tasmanian West	Zeehan	Granville Harbour	Regional Reserve	GHRR	82	4
	Pieman River	Pieman River	State Reserve	PRSR	83	6
	Port Davey	Davey River	National Park	DRNP	90	2
		James Kelly Basin	National Park	JKBNP	91	2
King	Arthur River	Arthur River	Public Reserve	ARPR	84	1
	Couta Rocks	Couta Rocks	Conservation Area	CRCA	85	2
	Nelson Bay	Nelson Bay	Conservation Area	NBCA	86	2
	Bluff Hill Point	Bluff Hill Point	Conservation Area	BHPCA	87	3
	Robbins Passage	Robbins Passage 1	Private Freehold	RP1PF	88	5
		Robbins Passage 2	Unidentified (Crown Land)	RP2CL	89	5

Chapter 3

Classification of coastal saltmarsh vegetation of Tasmania

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Chapter 3: Classifying coastal saltmarsh vegetation of Tasmania

3.1 Introduction

To survive the harsh conditions, saltmarsh plants must be able to endure frequent inundation by salt water and live in soils that are often waterlogged (Long & Mason 1983; Saintilan 2009b). A frequent claim made for saltmarsh vegetation is that it is species-poor. This impression is compounded by the dominance of a single species, or a few species, mostly in the lower marsh (Adam 2009; Saintilan 2009b) where, halophytic (salt tolerant), succulent plants dominate. These plants have adapted to the constant variations of salinity, moisture and at times anaerobic conditions to not only survive but also thrive (Long & Mason 1983). With increasing elevation of the substrate, the number of species tends to increase, especially in the upper marsh zones, where mixtures of halophytic and non-halophytic plants, as well as saline and woodland grasses, dominate alongside herbs (Long & Mason 1983; Adam 2009), a common feature of coastal marine marshes (Chapman 1974).

As a general rule, the tropics exhibit the greatest richness of plant species, with richness declining as latitude increases (Adam 2009). However, Australian saltmarshes show a very noticeable contrary pattern (Adam 2009; Saintilan 2009a). Australia's four southern states (Tasmania, Victoria, New South Wales and South Australia) are home to less than 2.5% of the total saltmarsh/saltpan area of Australia yet support over 90% of Australian saltmarsh species (Saintilan 2009a), with Tasmanian saltmarshes recording the highest number (Bridgewater & Cresswell 2003). Although there are affinities at family and genus level with saltmarsh taxa from other hemispheres and continents, Australian saltmarsh plants display a high level of endemism at species resolution (Adam 2009).

Vegetation patterns are conspicuous within saltmarshes, leading to what has been described as zonation (Long & Mason 1983; Adam 1990, 2009; Saintilan 2009b). Zonation is recognised in three broad classes – low, middle and upper marsh (Long & Mason 1983; Laegdsgaard 2006), often with distinct boundaries. In turn, this zoned arrangement of the saltmarsh reflects vegetation communities (Figures 3.1 and 3.2) and

is principally dominated by tidal aspects – daily diurnal tides, monthly high astronomical tides and sporadic storm surges.

Figures 3.1: Saline graminoid community containing *Austrostipa stipoides* (left), and woody succulents – *Tecticornia arbuscula* (right) and *Sarcocornia blackiana* as ground cover (Long Point).

Figure 3.2: Lowland graminoid community comprising *Lomandra longifolia* (left), saline grassland containing *A. stipoides* and *Poa* spp. (right) (Long Point).

3.1.1 Classification of vegetation communities

A common approach to classifying saltmarsh is to consider the vertical range within the saltmarsh and split this range into three zones, each supporting characteristic vegetation communities. The low marsh would include three or four species, with one species dominant, and there would be bare areas, the middle marsh containing more species, with the low marsh species present at reduced abundance, and the upper marsh comprising both salt and non-salt tolerant species (Long & Mason 1983).

Kirkpatrick and Glasby (1981) used structural forms to define Tasmanian saltmarsh communities as: (i) communities dominated by succulent shrubs – *Tecticornia arbuscula* – with low open heath of *Sarcocornia quinqueflora,* (ii) communities dominated by grasses, such as *Austrostipa stipoides,* (iii) communities dominated by sedges and rushes, such as *Gahnia filum* and *Juncus kraussii,* and (iv) communities dominated by herbs, such as *Samolus repens*.

Bridgewater and Cresswell (2003) identified diverse coastal saltmarsh communities on an Australian continental basis and recognised a specific Tasmanian subgroup within the main *Tecticornia arbuscula-Juncus kraussii* group (Bridgewater & Cresswell 2003). Work by Saintilan (2009a, 2009b) analysing Australia's coastal Interim Biogeographic Regions for Australia (IBRA) regions, revealed that with increasing latitude, the vegetation

richness of saltmarsh biogeographic provinces increased. Furthermore, Tasmania, as a whole, has more than half (53%) of Australia's saltmarsh flora with the island's South East bioregion containing 58% of the total flora (Saintilan 2009a) (Table 3.1). Add any buffer or woodland fringe to the saltmarsh and local species richness increases considerably.

Table 3.1: Percentage of coastal saltmarsh plants, identified as common throughout Australia, found in Tasmania's coastal IBRA6.1 bioregions. **Source:** Saintilan (2009a).

Tasmanian coastal bioregions *	% of common Australian saltmarsh plants found
Flinders (subregion of Furneaux)	55
Tasmanian South East	58
Tasmanian Southern Ranges	46
Tasmanian West	33
Tasmanian Northern Slopes	43
King	49

* see Figure 1.20 (Chapter 1) for Tasmanian (IBRA6.1) bioregions.

3.1.2 Tasmanian saltmarsh vegetation classification

Kirkpatrick and Glasby (1981) identified 15 vegetation community subgroups in Tasmanian coastal saltmarshes within four main vegetation classes. This classification was based on sampling vegetation communities in coastal saltmarshes in South East (SE) Tasmania. Plant associations from Kirkpatrick and Glasby (1981) study were not intended for Tasmania on a state-wide basis, but it did provide data on common saltmarsh plant distributions and local associations between plant species. However, SE Tasmania is only one of six coastal IBRA bioregions (Department of the Environment 2015) that contains saltmarshes and extrapolating data from this region is inadvisable because the remainder of Tasmania's coastal regions are likely to be dissimilar. From the work of Kirkpatrick and Glasby (1981), TASVEG, Tasmania's digital vegetation mapping service (Department of Primary Industries 2015) has classified Tasmania's coastal and inland saltmarsh vegetation in a binary manner, using ASS = Succulent saline herbland and ARS = Saline sedgeland/rushland (Department of Primary Industries 2015). A default code, AUS (Saltmarsh undifferentiated), is used if the vegetation has not been otherwise classified. Mapping and classification of saltmarsh areas in Tasmania have been based on a broad scale, particularly convenient when using aerial photography as a primary source. Generally, areas classified as ARS and ASS have been ground-truthed, however with improving imagery in recent years, many areas can

now be confidently identified as ARS or ASS from aerial photography (Prahalad & Kirkpatrick in press). Nevertheless, fine scale identification and classification has a place and is very important in saltmarsh research and conservation management.

With interest in Tasmanian saltmarshes increasing during the last ten years (e.g. Mount *et al.* (2010), Prahalad and Pearson (2013), Prahalad (2014), Ellison and Beasy (2018)), it is timely to seek an improved classification at a finer scale in order that current and future studies classify Tasmanian saltmarsh in a uniform and consistent manner. This need is apparent because climate change related sea-level rise is placing increasing pressure on coastal saltmarsh (termed "coastal squeeze"), which may in future alter the structure of saltmarsh vegetation communities or lead to total loss in some locations. Recent saltmarsh mapping on behalf of Tasmania's three National Resource Management (NRM) organisations (NRM South, NRM North and Cradle Coast NRM) by Prahalad (2014, 2015, 2016), has suggested that the classifications of Kirkpatrick and Glasby (1981) are inadequate to account for the range of variation evident in saltmarshes state-wide.

Therefore, it is important to carefully test to what extent the classifications proposed by Kirkpatrick and Glasby (1981) are an appropriate fit to all Tasmanian bioregions, and if not, new classifications for Tasmanian saltmarsh vegetation should be proposed. This will provide state-wide consistency in properly identifying saltmarsh vegetation communities in future research, saltmarsh restoration and monitoring.

3.1.3 Vegetation classification to a finer scale

The need to classify saltmarsh vegetation to a somewhat finer scale has been advocated at a continental/national level by Bridgewater and Cresswell (2003), and at a state level by Adam *et al.* (1988) and Boon *et al.* (2011).

On a national scale, Bridgewater and Cresswell (2003) identified five major saltmarsh groups, each divisible into sub-groups, using information from the Australian Virtual Herbarium (AVH), IBRA and previous syntaxonomic studies. Of the five groups, four either reference inland Australia (e.g. central arid or semi-arid regions, Murray-Darling Basin) or coastal areas of Western Australia and northern Australia. Group I – *Sclerostegia* (now *Tecticornia*)-*Juncus kraussii* Group – references southern Australian

coastline and Tasmania, hence will be the only group considered here. This group has four sub groups, each characterised by a suite of plant species (Table 3.2).

Table 3.2: Identifying species to sub-groups within I. *Sclerostegia* (now *Tecticornia*)-*Juncus kraussii* Group. Groups II., III., IV. and V. are not included as they represent inland, western and northern coastlines of Australia. Only sub-groups I.1 and I.2 are applicable to Tasmania. **Source:** Bridgewater and Cresswell (2003).

Group	Sub-group	Range	Species
I. *Sclerostegia arbuscula- Juncus kraussii*		Southern Australia coastline and Tasmania	
	I.1 *Stipa stipoides-Selliera radicans*	Confined to western Tasmania	*Stipa* (now *Austrostipa) stipoides, Apium prostratum, Atriplex paludosa paludosa*
	I.2 *Stipa stipoides-Agrostis* (now *Lachnagrostis) billardieri*	Confined to eastern Tasmania and SE Australia to northern NSW	As for I.1 plus *Limonium australe, Wilsonia backhousei, Agrostis* (now *Lachnagrostis) billardieri, Gahnia filum*
	I.3 *Halosarcia halocnemoides-Limonium binervosum*	Confined to central southern Australian coast	*Triglochin mucronatum, Sarcocornia blackiana, Halosarcia halocnemoides, H. pergranulata,* plus *Limonium binervosum, H. flabelliformis, Maireana oppositifolia*
	I.4 *Halosarcia halocnemoides-Rhagodia baccata*	Confined to south-west Australian coast	As for I.3 (first 4 species) plus *Atriplex hypoleuca, Rhagodia baccata, Frankenia tetrapetala, H. indica bidens, H. pterygosperma pterygosperma, Atriplex paludosa baundinii*

At the IBRA bioregional level, Bridgewater and Cresswell (2003) have demonstrated that climate variables play a role in the distribution of saltmarsh vegetation groups. Similarly, Deil (2000) noted there is a strong geographical distribution of plant species linked to climatic variations of the Arabian Peninsula coast as Fariña *et al.* (2018) has noted for the Chilean Pacific coast. Within the Australian context, the I.1 *Stipa* (now *Austrostipa) stipoides-Selliera radicans* sub-group is confined to western Tasmania, an area of high rainfall, constantly moist and cool climate (Bridgewater & Cresswell 2003), whereas the current distribution of I.2 *Stipa* (now *Austrostipa) stipoides-Agrostis* (now *Lachnagrostis) billardieri* sub-group, ranging from eastern Tasmania to the SE coast of the Australian mainland (Bridgewater & Cresswell 2003), may reflect the biogeographical legacy of Tasmania being part of the Australian landmass during the last glacial period (Corbett 2014).

Thus, the work by Bridgewater and Cresswell (2003) provides an overview of saltmarsh plant distribution at the continental/landscape scale, but it also clearly demonstrates that the generic term "saltmarsh" obscures the fact that species composition in saltmarshes alters latitudinally as well as longitudinally and that "key biogeographic fulcra" (Bridgewater & Cresswell 2003, p. 248) appear to determine saltmarsh vegetation groups.

Adam *et al.* (1988) has recommended that a floristically based classification of New South Wales central coast marshes (Table 3.3), aligned to Bridgewater (1982), be applied "to allow a comparison between sites and as a basis for the study of other aspects of saltmarsh ecology" (my emphasis) (Adam *et al.* 1988, p. 35).

In NSW, saltmarsh vegetation communities are species poor and generally made up of a mix of just four species, *S. quinqueflora, S. repens, Sporobolus virginicus* and *Triglochin striata*. Data from 394 saltmarsh relevés were analysed and clustered using COMPCLUS (Gauch 1979) into 55 groups of which 24 contained only one relevé. Three major groups were recognised, associated with the dominance of *S. quinqueflora, S. virginicus* and *J. kraussii*. Adam *et al.* (1988) felt it suitable to aggregate groups "into a smaller number at a higher order" (Adam *et al.* 1988, p. 50) so that workers in field studies of NSW saltmarshes would find it possible to match data to these higher order groups if they could not compare data at a lower order. When comparing results with Bridgewater (1982), Adam *et al.* (1988) had to omit a number of Bridgewater's orders as defining taxa (in the omitted orders) were not present in NSW, thus leaving two orders in one class. The two remaining orders were split into four alliances and these divided into a total of 15 units/sub-units (see Table 3.3). Adam *et al.* (1988) also proposed three additional alliances – Paspalion vaginati, Cyperion laevigati and Zoysion macranthae that could not be attached to a class or order.

Table 3.3: Proposed phytosociological classification of Central Coast (NSW) saltmarsh communities. **Source:** Adam *et al.* (1988).

Class	Order	Alliance	Unit	Sub-unit
SAMOLO – SUAEDETEA (Bridgewater 1982)	Samolo – Suaedetalia (Bridgewater 1982)	Sarcocornion quinqueflorae (Bridgewater 1982)		sarcocornietosum
				triglochinetosum
				sporoboletosum
			Wilsonia backhousei community	
			Samolus repens community	
		Sporobolion virginici (alliance nov.)	Sporoboletum virginici	
			Selliera radicans community	
	Triglochino – Disphymetalia (Bridgewater 1982)	Stipo – Juncion (Bridgewater 1982)		
			Juncetum kraussii (Bridgewater 1982)	*Juncus kraussii* dominated community
				Juncus kraussii – *Sporobolus virginicus* community
				Juncus kraussii – mixed marsh
				Juncus kraussii – *Suaeda australis* community
			Gahnio – Juncetum (Bridgewater 1982)	
			Juncus kraussii brackish pastures	
		Baumion juncea (alliance nov. prov.)	*Baumea juncea* community	
			Baumea juncea – *Juncus kraussii* community	

In Victoria, classification of vegetation into groups called Ecological Vegetation Classes (EVCs) is based on floristic, structural and ecological features. Victorian coastal saltmarshes have a general (generic) classification – Coastal Saltmarsh Aggregate (EVC9). However, saline wetlands and communities that fringe coastal saltmarshes are also included in 14 other classes (Boon *et al.* 2011). These include brackish grassland

(EVC934), brackish wetland (EVC656) and saline aquatic meadow (EVC842). The term "aggregate" (used above) "is applied to an EVC label where the EVC represents a generalised label for wetlands occurring within a given ecological context (e.g. saline, brackish or freshwater lakes; billabongs; mineralised drainage lines on grey-clayed basalt derived soils)" (Boon *et al.* 2011, p. 235). Thus, using the term "aggregate" provides a generalised description for a broad mapping unit used in a landscape situation, but does not define vegetation classes to a finer scale, one that can be used in ecological studies. Furthermore, a broad-scale generalised classification does not allow for a reference framework for the monitoring of saltmarshes, nor allow identification of those vegetation communities that have serious conservation values, particularly those that are under pressure from (anthropogenic) coastal development (Boon *et al.* 2011), and/or those that may be identified as conservation hotspots. To rectify the current anomaly of using "Coastal Saltmarsh Aggregate" as a descriptor, Boon *et al.* (2011) used data from over 2000 plots of saline coastal communities and fringing zones and hand sorted these to either EVCs or structural dominant groups.

A final dataset of 483 plots was sorted into a total of 37 groups of which 19 fitted into Coastal Saltmarsh Aggregate. It was observed that there were "…geographical gaps within the dataset… and some of the structural range is poorly represented…" (Boon *et al.* 2011, p. 240). Following field validation that identified missing species, a final dataset was analysed to produce a two-way table and from this a revised typology was created that better reflects coastal saltmarsh vegetation communities in Victoria (see Table 3.4, following page). Additionally, coastal bioregions were identified as well as current conservation status of each community. Furthermore, Boon *et al.* (2011) have suggested that the proposed new Ecological Vegetation Communities reside within the existing Coastal Saltmarsh Aggregate rather than being an addition within the overall vegetation framework of Victoria.

Undoubtedly, the Victorian experience demonstrates that it is somewhat difficult to align, or even use, an overall generic classification of saltmarsh vegetation in each state without removal, or addition, of some classes, or the alteration of others, when either comparing to a nationwide classification or to individual state classifications. As saltmarsh plant species richness increases with increasing latitude (Saintilan 2009a), it is prudent to consider classification of Tasmanian coastal saltmarsh vegetation

communities as stand-alone. However, some attempt should be made to align Tasmanian classification within an overall structure, for example, that of Bridgewater and Cresswell (2003).

Table 3.4: Proposed new EVC for Victorian coastal saltmarshes. **Source:** Boon *et al.* (2011).

Proposed EVC	Distinguishing features	Floristics	Structure
Wet Saltmarsh Herbland	Low herbland dominated by succulent to semi-succulent halophytic herbs or semi shrubs	Dominated by *S. quinqueflora,* less common occurrence by *Hemichroa pentandra, Selliera radicans, S. repens, Suaeda australis*	Low herbland up to 0.3m, or infrequent shrubland to 1m
Wet Saltmarsh Shrubland	Shrubland dominated by halophytic species, subject to regular inundation	Dominated by *T. arbuscula*, less common by *Atriplex paludosa*, rarely by *Atriplex cinerea*. *S. quinqueflora* frequent in wetter communities, with *T. arbuscula*, less abundant in slightly more elevated communities	Shrubland to 2m (rarely to 3m), frequently around 1m when dominated by *T. arbuscula*
Coastal Saline Grassland	Grassland dominated by rhizomatous grasses (forming mounds), occurring to upper zones of coastal saltmarsh	Species poor dominated by either *Distichlis distichophylla* or *S. virginicus. S. quinqueflora* frequent association with *D. distichophylla*	Turf grassland, maximum development to 1m mounds, often lower
Coastal Dry Saltmarsh	Herbland to low shrubland of upper marsh, relatively infrequent tidal inundation	Variously dominated by *Sarcocornia blackiana, Disphyma crassifolium* and others*. S. quinqueflora* often present with *S. repens, H. pentandra, S. australis*	Low shrubland or herbland usually less than 0.3m
Coastal Hyper-saline Saltmarsh	Low shrubland dominated by succulent chenopods occurring in highly hyper-saline saltmarsh habitat	Dominated by *Tecticornia pergranulata, Tecticornia halocnemoides* and bare ground, very locally by *Lawrencia squamata*. Can be very species poor. Can include *S. quinqueflora*	Low shrubland or open shrubland, less than 1m high
Coastal Tussock Saltmarsh	Upper saltmarsh zones dominated by robust tussock-forming grasses or graminoids	Dominated by either *G. filum* or *A. stipoides.* Ground cover species include *S. quinqueflora, S. repens, S. australis*	Tussock sedgeland to ~2m or tussock grassland to 1.5m
Saltmarsh-grass Swamp	Inundation prone vegetation dominated by *Puccinellia stricta* (Australian Saltmarsh-grass)	Dominated by *P. stricta*, associated lower cover species include *S. quinqueflora, S. australis, T. pergranulata, G. filum, Wilsonia humilis* and *Wilsonia rotundifolia*	Tussock grassland usually to 0.3m high

3.1.4 Questions and study aims

At present, saltmarsh vegetation communities, both inland and coastal, are classified by TASVEG 3.0 as ASS, ARS or AUS. Another classification, AWU (Wetland undifferentiated), although identified as wetland rather than on occasions (more accurately) as saltmarsh, also falls within the saltmarsh classification (see Table 3.5).

While useful at a very broad (state-wide/landscape) scale, these codes have limited utility at a finer scale useful for ecological research.

Questions

1. Is there an unacceptable variability encountered in current saltmarsh (coastal and inland) TASVEG vegetation community classifications (ASS and ARS) across Tasmania?
2. Are the current classifications (ASS and ARS) suitably defined to enable consistency in saltmarsh research, restoration and monitoring?
3. Do Tasmanian saltmarsh vegetation communities conform to any type of pre-existing natural regionalisation?

Study aims

- Delineate and describe coastal saltmarsh vegetation communities at a fine scale;
- Develop a key to aid field interpretation of coastal saltmarsh vegetation communities;
- Place coastal saltmarsh vegetation communities into a simplified hierarchical framework;
- Create a refined typology of the proposed vegetation communities that is compatible for use with TASVEG; and
- Determine the best regionalisation/classification (as described in Chapter 1: Introduction. Regionalisation of Tasmania's natural areas) that represents the natural variation of Tasmanian coastal saltmarshes throughout the State.

3.1.5 TASVEG Codes (current)

Current TASVEG 3.0 codes used to classify coastal saltmarsh vegetation throughout Tasmania are presented in Table 3.5.

Table 3.5: TASVEG 3.0 codes currently applied to saltmarsh vegetation. **Source:** Kitchener and Harris (2013). Note: the authors use the terms herbfield and herbland interchangeably.

ARS = Saline sedgeland/rushland – *G. filum* (tussock sedgeland), *J. kraussii* (open rushland), *Leptocarpus* (now *Apodasmia) brownii* (open rushland).
ASS = Succulent saline herbland – *T. arbuscula* (heath), *S. australis* (heath), *S. quinqueflora* (low open heath), *S. blackiana* (low open heath), *H. pentandra* (low open heath), *D. crassifolium* (succulent herbland), *Wilsonia backhousei* (herbland), *S. repens* (herbland).
AUS = Saltmarsh (undifferentiated) – as for ASS and ARS – this code "used where field access is not possible and remote allocation to a more specific unit is not advised" (Kitchener & Harris 2013, p. 15).
AWU = Wetland (undifferentiated) is used where separation using remote mapping methods has not been possible. This code "used where field access is not possible and remote allocation to a more specific unit is not advised" (Kitchener & Harris 2013, p. 18)

Examples of vegetation subgroups within TASVEG 3.0 classification ASS, demonstrating the range of diversity within that classification, are displayed in Figures 3.3 to 3.6. Each of the images below is classed ASS as identified from aerial photography.

Figure 3.3: *Sarcocornia quinqueflora* (Long Point).

Figure 3.4: *Tecticornoa arbuscula* and bare ground (Long Point).

Figure 3.5: *Sarcocornia quinqueflora* (left, bright green colour), *Sarcocornia blackiana* (right, blue green colour) and *Disphyma crassifolium* (bottom centre and throughout, reddish brown colour) (Long Point).

Figure 3.6: *Tecticornia arbuscula* with *Sarcocornia quinqueflora* as ground cover (Long Point).

Examples of vegetation subgroups within TASVEG 3.0 classification ARS, demonstrating the range of diversity within that classification, are displayed in Figures 3.7 to 3.10. The images below are all classed as ARS.

Figure 3.7: *Juncus kraussi* (Deephole Bay).

Figure 3.8: *Austrostipa stipoides* (a graminoid) with *Sarcocornia quinqueflora* ground cover (Long Point).

Figure 3.9: *Gahnia filum* (foreground, centre, brown green colour), *Austrostipa stipoides* (throughout, yellow green colour) (Long Point).

Figure 3.10: *Austrostipa stipoides* and *Juncus kraussii* (dark brown seed heads) (Pipe Clay Lagoon).

Note, in this context ARS can include halophilic understorey/groundcover species, they being non-dominant within this vegetation community. This generates confusion when assessing saltmarsh vegetation at a finer scale.

3.2 Methods

It is relatively straightforward to select several coastal saltmarsh sites, carry out a vegetation assessment at each, use statistical analysis to classify vegetation communities, and produce a vegetation community identification key. However, how accurate will it be, and will it properly reflect the vegetation community diversity visually appreciated in

the field on a state-wide basis? To produce a robust product that will withstand application in the field, this study was carried out in three phases:

- Phase 1 – formulate a draft saltmarsh vegetation community key using Training sites (those listed in Chapter 2: Defining Tasmanian coastal saltmarshes and detailing study sites) on a state-wide basis;
- Phase 2 – apply the draft key at a selection of Test 1 sites (listed in Chapter 2), principally those located in regions most populated by coastal saltmarshes; prepare an updated and improved proposed saltmarsh vegetation community key; and
- Phase 3 – apply the proposed key to a range of Test 2 sites (listed in Chapter 2), ideally located state-wide; aggregate the data from Training, Test 1 and Test 2 sites to create a Combined dataset and prepare a final vegetation community key that will be applicable and useful on a state-wide basis.

3.2.1 Transects and plots (sampling units)

Site assessment was based on identifying mappable vegetation communities within the marsh. Transects were located to capture as much of the vegetation variation as possible and cross each site either from land to water's edge or vice versa. Wherever practical, vegetation sample plots were placed in a uniform and representative location within a vegetation community, an acceptable practise when using a cover-abundance assessment method (Kent 2012). Care was taken to position the plot away from transition boundaries between two vegetation communities to avoid edge effects. Plot size was selected following the general guidelines based on the vegetation types expected to be assessed (Kent 2012). In this case, expected vegetation communities could be defined as succulent herbs, shrubby heaths, tall herbs and grasslands, and grasslands with dwarf herbs. The suggested plot size of 2 x 2 metres (Kent 2012) was used throughout all field work.

Plots were identified by position along each transect; such as, ABPR 2 – AB = Acton Bay, PR = Public Reserve, 2 = 2nd plot along transect. In some instances, two transects were located at a site, in this case plot identification includes the transect number; for example, LPCC 2-3 – LP = Long Point, CC = Conservation Covenant, 2 = second transect, 3 = 3rd plot along transect.

3.2.2 Vegetation assessment

Vegetation data can be recorded as incidence (presence/absence), or by cover/abundance (percentage cover in each plot) (Kent 2012). A widely used vegetation assessment method is the Braun-Blanquet cover-abundance measure that ranks species on an ordinal scale (Jongman *et al.* 1987; Kent 2012; Peet & Roberts 2012; Wildi 2013). This cover-abundance method expresses a value based on individual species form and content. At lower species densities the values relate to abundance of single species, whereas, at greater densities, values relate to the percentage of individual species (Wildi 2013). In this study, the cover values were scaled as follows:

0 = not present, 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = >75%.

Cover was estimated by eye as a percentage, however with stratification and multiple layering total cover values often exceeded 100%, a common occurrence using this method (Moore & Chapman 1986; Kent 2012), and regularly experienced throughout this study. All vegetation assessments were conducted by the same assessor to provide uniformity throughout the study and to minimise the over/under estimation of cover. Plant species identification was conducted *in situ*, aligned with Prahalad (2014), and nomenclature updated to de Salas and Baker (2018). Unidentified species were vouchered, and identification conducted *ex situ*.

Additionally, plot GPS coordinates were recorded to enable relocation in the future. Plant species cover abundance values, aligned with plot codes were entered to a spreadsheet along with coordinates for each of the Phases.

Vegetation assessments took an inordinate amount of time, it was not unusual to take two days just to complete one site including travelling time (e.g. travelling to Launceston Airport, flying to King Island, returning to Launceston and driving to Hobart). Phase 1 involved 48 days, Phase 2 required 53 days and Phase 3 required 95 days of field work, totalling nearly 200-person days.

3.2.3 Climatic variables

Variations in climate, particularly annual precipitation and the temperature range, can have a bearing on the distribution of plant species. In Australia, it is the amount, timing and duration of rainfall that appears to be a major factor in saltmarsh plant species

distribution (Bridgewater & Cresswell 2003). Deil (2000) and Fariña *et al.* (2018) also noted that climatic variables were a strong link to phytogeographical difference in halophyte distribution. Similarly, alterations in precipitation range and rates may impact the distribution and future survival of saltmarsh vegetation (Watson *et al.* 2015).

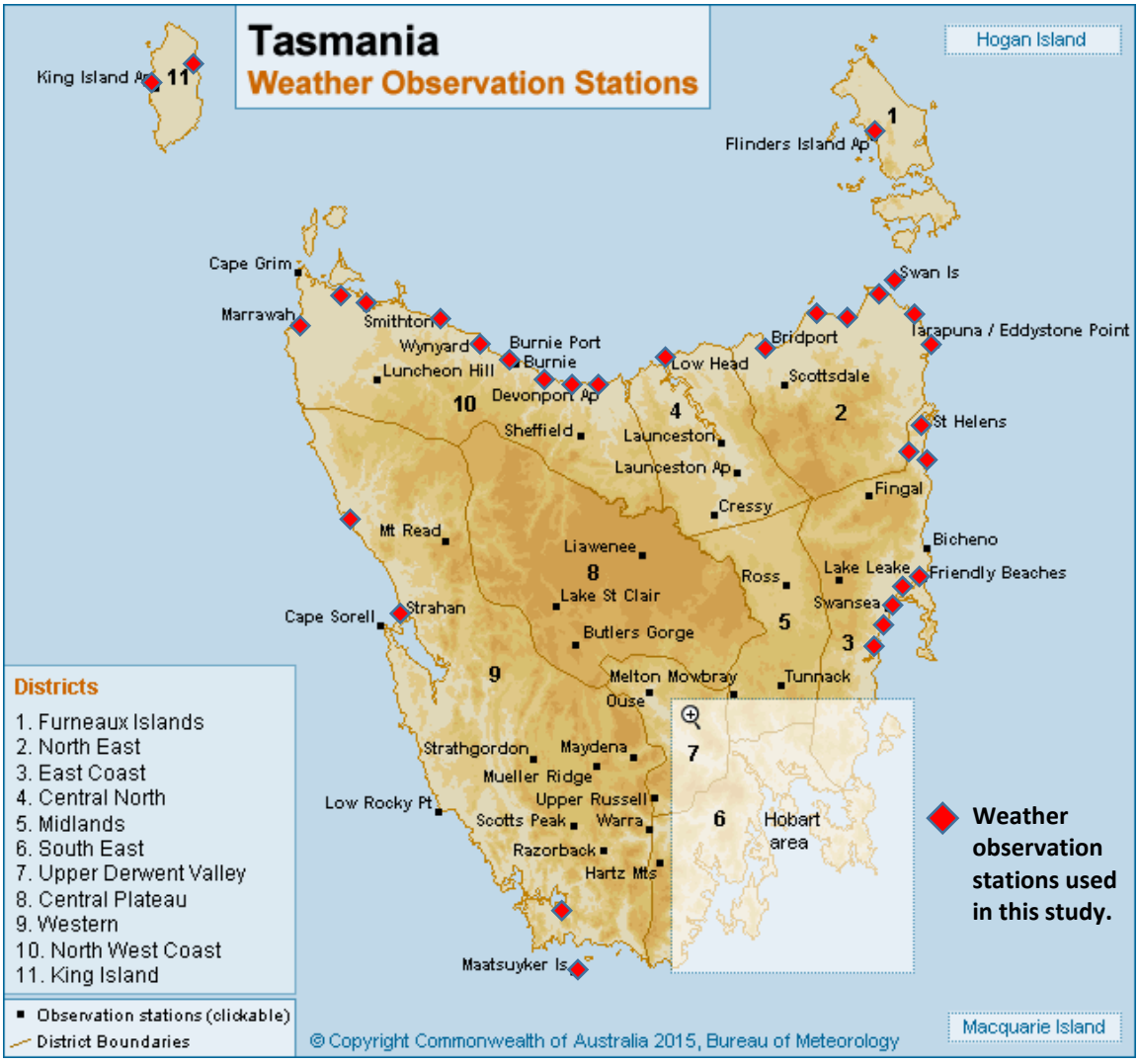
The Bureau of Meteorology (BOM) operates manual and automatic weather recording stations along Tasmania's coast (Figures 3.11 and 3.12) from which current and long-term data can be accessed. Weather observation stations linked to study sites are presented in Appendix 3A.1.

Unfortunately, the period of recording (years) is not consistent throughout the state, both in terms of temperature data and rainfall data. For example, Flinders Island Airport has temperature for 54 years and rainfall data for 73 years, whereas, King Island Airport has temperature data for 21 years and rainfall data for 39 years. Obviously, long-term data consistency is not possible between all the stations, however, to understand the variations across all locations, all data, irrespective of timeframes, from each observation station were used.

Climate data accessed includes: rainfall – long-term mean annual at decile 5 (medium)[29], annual lowest (lowest annual recording during period) and annual highest (highest annual recording during period); temperature – long-term mean annual maximum and minimum[30], annual lowest and highest (recorded during period) of each maximum and minimum, lowest and highest monthly means; and solar exposure – mean highest and lowest daily (recorded during period) of each.

[29] The median, or term Decile 5, rainfall is that value which marks the level dividing the ranked dataset in half; i.e. the midpoint of the ordered (lowest to highest) monthly or yearly precipitation totals. To determine decile 5 of a series of observations, they are first arranged in order from lowest to highest, and then divided into 10 equal groups. Decile 5 is the value at the top of the 5th grouping; in other words, the middle value in the ranking. In 50% of the years on record the monthly or yearly rainfall total was lower than the decile 5 value. The median is usually the preferred measure of 'typical' rainfall from the meteorological point of view. This is because of the high variability of rainfall – one extreme rainfall event will have less effect on the median than it will have on the arithmetic mean (my emphasis) (BOM 2016).

[30] The average daily maximum and minimum air temperature for each month and as an annual statistic calculated over all years of record (BOM 2016).



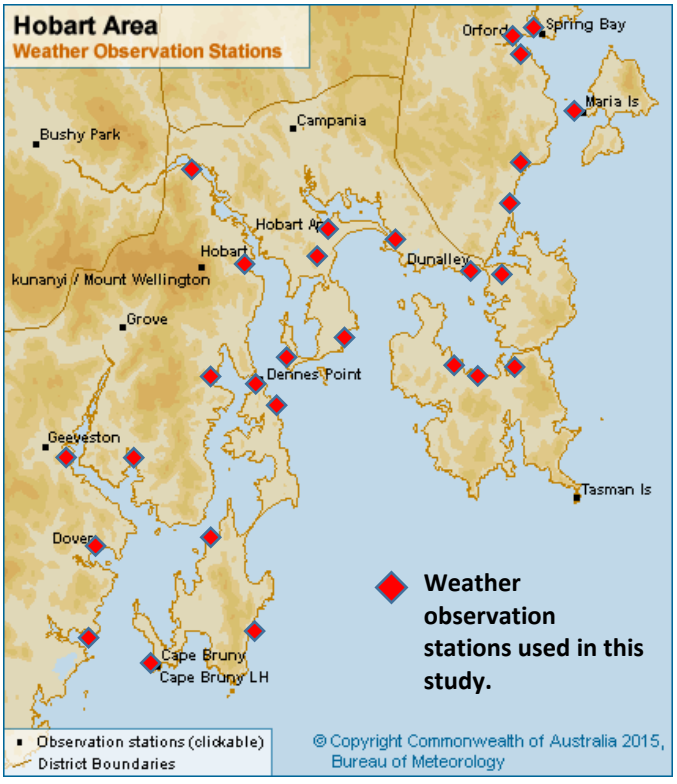


Figure 3.11: Tasmania weather observation stations.

Observation stations selected are those that are the most appropriate fit for the study site (closest, coastal, aspect, etc.) and those that are still open and recording daily weather observations of temperature (maximum and minimum), rainfall or those that have been open until recently and have long-term data available.

Figure 3.12: Hobart area weather observations stations.
Source: BOM (2016b).

The data collected above were assigned to each respective site (see table Appendix 3A.1), therefore each plot at each individual site was allocated the same weather data. For example, each plot (5 of) at Little Forester River has identical weather data, this sourced from Bridport weather station. Furthermore, several sites have been assigned the similar weather data as each is near the same weather observation station (and to each other), for example, Lowana Point, Cat Island and Mill Bay (all sites within the Tasmania West bioregion) have been allocated identical data sourced from Strahan Airport weather observation station. This is the closest weather station to the study sites and is representative of the locality.

3.2.4 Vegetation community keys

One essential outcome of this study was to design a vegetation community key that would allow workers in the field, with a reasonable knowledge of plant identification and/or access to a plant guide (Prahalad 2014), to correctly recognise and name coastal saltmarsh vegetation communities. The use of the key would standardise vegetation community naming during further studies whether by researchers or citizen groups. Data collected by vegetation group could then easily be compared with a similar named vegetation group and against other groups and support ongoing research in this field. This would standardise collected data and become useful when documenting spatial or temporal change particularly that caused by climate change and/or sea-level rise.

Accuracy of draft and proposed keys

This section refers to Phase 2 and Phase 3, where the suitability and accuracy of each key was assessed.

The field classification column in the vegetation assessment spreadsheet was "hidden" (by means of the "hide" column feature in MS Excel). From a desktop approach, each plot was assigned a vegetation community code based on the draft/proposed key and recalled field observations. To maintain continuity of the vegetation assessment between Training, Test 1 and Test 2 sites, this task was completed by the assessor of the Training sites cover abundance vegetation assessment. Once coded, the field classification column was "unhidden" and field results compared to desktop results. A reliability factor of the draft/proposed key was then calculated.

Draft/proposed key improvements

Following review of the comparison between field and desktop vegetation community codes, any anomalies within the draft/proposed keys were identified and consideration given to the ecological fit in the field. Deliberation was also given whether any vegetation group had been "overlooked" and had been assimilated into another group with little justification.

3.2.5 Hierarchical structure

A simple hierarchical vegetation structure for coastal saltmarsh vegetation was constructed based on statistical analysis of data and evidence from the field. The aim of the structure was to organise the plant communities, as defined by the cluster analysis, into an intuitive framework (Perrin 2015) that would offer users a ready-made visual structure of order and also provide an appraisal of saltmarsh plant communities.

The proposed hierarchy has not been tightly aligned to any existing hierarchy, however the higher classification levels are loosely based on Faber-Langendoen *et al.* (2012) used by the International Vegetation Classification. The upper three levels of the hierarchy are based on physiognomy, with the lower three levels based on floristics (Perrin 2015):

- Class – divides vegetation on dominant life forms, for example, shrubs and herbs;
- Formation – divides vegetation to either inland or coastal representing the major biogeographical regions of Tasmania, such as, coastal shrubs and herbs;
- Division – aligns dominant life forms to habitat types, such as, saltmarshes;
- Group – represent broader divisions based environmental gradients (e.g. pH), such as, graminoids and succulent herbs;
- Community – a fundamental division reflecting specific differences of the floristic composition, for example, graminoids (dominant) with succulent herbs; and
- Sub-community – divides communities based on indicator species, or subtle variations based on floristics, such as, graminoids (dominant) – *A. stipoides, Ficinia nodosa* and succulent herbs – mix such as *D. crassifolium* and *Sarcocornia blackiana.*

3.2.6 Revised typology for ASS and ARS

A revised typology for TASVEG 3.0 codes ASS and ARS was then produced based on the clustering outcomes. The proposed typology follows Boon *et al.* (2011) and is aligned to TASVEG 3.0. Bioregions were identified for each group with additional information on species as follows:

- Known conservation status for individual plant species, that is, if listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and/or the Tasmanian *Threatened Species Protection Act 1995* – reference should be made to official legal documents for any latest inclusions;
- If endemic to Tasmania, or Australia, but only now found in Tasmania;
- If introduced, or, a declared weed; and
- Any other information relevant to the classification or plant species.

Plant species nomenclature conforms to the current *Census of vascular plants of Tasmania* (de Salas & Baker 2018).

3.2.7 Vegetation communities and natural regionalisation

The term "regionalisation" also incorporates classification types (e.g. estuarine classification), and the term "region" includes classes, those defined within classification types. Various types of natural regionalisation used in Tasmania have been outlined in Chapter 1. Of these, IBRA6.1, IMCRA3.3, BOM coastal districts, geographic (Edgar *et al.* 1999) and estuarine classification (Edgar *et al.* 1999) were identified as appropriate, either through strong coastal connections or clearly related to estuarine systems, for study into the relationship between vegetation communities and regionalisation types.

Vegetation community indicators

The vegetation community classification established earlier (see Section 3.2.4/3.3.2) was used to determine the indicator communities for each regionalisation type. Natural regionalisations were aligned to individual vegetation communities.

Determination of the best fit

Each regionalisation was examined for specific differences in terms of the numbers of individual vegetation communities aligned to separate regions (within each individual regionalisation). Additionally, the significance of the specific alignment (p-values) was evaluated to determine which regionalisation type best describes coastal saltmarsh vegetation patterning.

3.3 Statistical analysis

Statistical analysis of collected vegetation data allows a better understanding of the complexity of vegetation systems and dynamics, and an appreciation of the real world (Wildi 2013). Analysis provides the recognition and interpretation of vegetation patterns (Wildi 2013), in turn permitting the development of models that can be used to predict future outcomes (Kent 2012), such as impacts of climate change and sea-level rise. Examples of statistical analysis include: data screening, classification and clustering, ordination by principal components analysis (PCA) and by non-Multidimensional scaling (nMDS), testing of differences between groups, and group indicator species (see http://ecology.msu.montana.edu/labdsv/R/labs/, http://www.umass.edu/landeco/teaching/multivariate/schedule/multivariate_schedule.html and https://sites.google.com/a/uw.edu/fish560/).

Finally, defined vegetation communities were aligned to precipitation, temperature and solar exposure data to determine if any key climatic drivers were responsible for the occurrence of particular vegetation communities of individual plant species, this prospect highlighted by Bridgewater and Cresswell (2003) in relation to IBRA bioregions, and Deil (2000) and Fariña *et al.* (2018) in their respective studies (Arabian Peninsula and Chile respectively).

The goal of the statistical analysis was to use good contemporary practice in identifying the appropriate grouping of coastal saltmarsh vegetation of Tasmania. Books and manuscripts by Faith *et al.* (1987), Clarke and Warwick (2001), Lepš and Šmilauer (2003), Aho *et al.* (2008), Borcard *et al.* (2011), Kent (2012) and Wildi (2013) were extensively consulted for best practice in the statistical analysis of vegetation data. The analyses were conducted using the statistical analysis program R (see www.cran.r-project.org), (R Core Team 2014) principally employing packages `cluster` (Maechler

et al. 2014), `ecodist` (Goslee & Urban 2007), `gclus` (Hurley 2012), `labdsv` (Roberts 2015), `simba` (Jurasinski & Retzer 2012) and `vegan` (Oksanen *et al.* 2013).

The sequential analysis/testing steps undertaken for each Phase and the aggregated data were as follows:

Phase 1:

1. Data screening;
2. Numerical classification and cluster analysis including multivariate resemblance/comparison;
3. Production of a dendrogram to aid visual interpretation of proposed classes;
4. Development of a draft vegetation community identification key; and
5. Desktop verification of that key.

Phase 2:

6. Test the efficacy of draft key in the field (Test 1 sites);
7. Desktop verification of the applied vegetation codes; and
8. Modify/improve the draft key and prepare as a proposed key.

Phase 3:

9. Test the efficacy of the proposed key in the field (Test 2 sites);
10. Desktop verification of applied vegetation codes; and
11. Modify the proposed key to a final key.

The following were undertaken after combining the Training, Test 1 and Test 2 datasets:

Combined:

12. Data screening;
13. Ordination –
    a) Principal components analysis (PCA);
    b) Non-metric Multidimensional scaling (nMDS);

14. Response to climate variables;
    a) Indicator species by individual species;
15. Preparation of the final vegetation community key;
16. Construction of a simple plant species hierarchical structure; and
17. Creation of a new typology compatible with the current TASVEG 3.0.

On completion of vegetation data analysis, vegetation community classes identified above, were aligned to soil characteristics to determine the range of conditions that individual vegetation communities tolerated (see Chapter 4: Soils of Tasmanian coastal saltmarshes).

3.3.1 Data screening

Vegetation data was screened for errors, such as, missing plots, empty cells etc. Once completed, data was analysed for:

- Species occurrence and mean cover by plot;
- Species frequency (histogram);
- Species richness and total cover by plot;
- Species cover and average number of species; and
- Mean species cover as a function of species presence.

3.3.2 Classification and grouping

Numerical classification

Vegetation is the most discernible and easily assessable component of a saltmarsh. The principal species that make up the individual vegetation communities do not change season by season (Goodall 1978). Dominant plants, such as *Sarcocornia* spp. *T. arbuscula* and *J. kraussii* are easily identifiable in the field. The majority of the key coastal saltmarsh plants species in Tasmania are recognisable, even by those with limited species identification knowledge (an excellent plant guide book is available – see Prahalad (2014)). Furthermore, saltmarsh vegetation communities are generally well defined, often have distinct boundaries, and in future, communities will be

distinguishable by use of a key. Vegetation assessments do not require the collection and analysis of environmental factors such as soils, saving significant time and resources (Kent 2012). Therefore, it is beneficial to use vegetation communities to cluster the plots into vegetation community classes and later align with soil characteristics.

Classification is a set of rules that governs the grouping of plots together, therefore, if one dataset is used with the same method the same result should be obtained each time (Goodall 1978; Kent 2012). The goal of classification is the "natural grouping" (Clarke & Warwick 2001, pp. 3-1) or clustering of individual plots/sites/relevés into classes based on similar species composition (internally homogeneous) (Lepš & Šmilauer 2003) and abundance of those individual species (Kent 2012). A cluster analysis grouping can be used to define species community complexes, that is, groups of species that co-exist in a parallel mode across sites (Clarke & Warwick 2001).

However, there are several methods available for clustering vegetation data, each providing a different, though somewhat similar, result. As no single process is the best in clustering vegetation data, the "best outcome" is one that provides a clear ecological interpretation (Kent 2012, p. 308) of the analysed dataset, one that provides a "best fit based on statistical analysis" of the cover abundance data in combination with a "best fit from a field-based viewpoint" (Goodall 1978, p. 280). This includes a visual appraisal and first-hand knowledge of the study sites.

When a numerical classification is applied to a vegetation dataset, it is anticipated that some grouping structure will be present along with the existence of distinct vegetation (Kent 2012).

Clustering approaches

Generally, classification and grouping of vegetation data uses hierarchical methods, but non-hierarchical methods do exist, though not often used in ecological applications (Kent 2012).

Non-hierarchical

The main purpose of non-hierarchical clustering is to summarise redundant plots into fewer groups for future analysis by placing each (similar) plot to a cluster (McGarigal

2000). This clustering procedure does have limitations, which include assuming equal covariance matrices among groups, and strongly biased towards spherical and elliptical shape clusters (McGarigal 2000). Various methods are available for describing best classification; of these, two are important – a) maximal predictive classification, and b) minimum within group sum of squares (Digby & Kempton 1987; McGarigal 2000).

Maximal predictive classification is only recommended for use on binary datasets, the method classifying plots based on presence/absence (Digby & Kempton 1987). This is somewhat troublesome as rare and fewer common species are attributed the same weight as more common species.

Minimum within group squares is used for classifying plots to a pre-determined (by the analyser) number of clusters by allocating plots to a cluster and at the same time maintaining the within group sum of squares at a minimum (Digby & Kempton 1987; Kent 2012). Although this method is not suitable for data containing rare species it can be useful in conjunction with ordination (Kent 2012).

K-means is one such non-hierarchical method that uses the minimum within group squares approach. Although widely used, it is not recommended for ecological data because it requires the pre-selection of the number of clusters at the outset (Kent 2012), and the number of clusters is often unknown in advance. However, k-means is a good starting point to investigate clustering and consider possible outcomes. Generating a series of analyses with resultant scree plots, can assist in the determination of an appropriate number of suitable clusters, which can then be used to consider the preferred number of suitable clusters when one runs the analysis using hierarchical clustering methods. It must be remembered that k-means always begins from a different seed (starting point) and generally no two repetitions yield the same result.

The function `cascadeKM` is an add-on to k-means clustering, acting as a "wrapper" for the `kmeans` function and is from the package `vegan` (Oksanen *et al.* 2013, p. 42). This function creates several partitions that form a cascade from small to large values of k (range of the number of clusters), as set by the analyser. A side plot displays simple structure index (ssi) criterion values for each number of groups with a recommendation for number of groups. The ssi criterion is a good estimate of the best partition available for the data following non-hierarchical clustering (Borcard *et al.* 2011).

Hierarchical

Generally, hierarchical methods are preferred for vegetation data (Kent 2012; Wildi 2013). The results are displayed as a dendrogram which show levels of similarity/ dissimilarity, thus making it helpful in determining the position of the cut (Kent 2012; Wildi 2013). However, care must be taken when interpreting the resulting dendrogram as all branches are in "spin", therefore closeness of groups does not imply similarity (Wildi 2013, p. 56), an important point to appreciate.

Agglomerative techniques are widely used in hierarchical methods (Wildi 2013). The process starts with individual plots and progressively combines them based on similarity until all are aggregated to one large group (Kent 2012; Peet & Roberts 2012; Wildi 2013). Hierarchical clustering, when run using the same method and similarity/ dissimilarity measure, will always produce the same result, contrary to using k-means (see above). Before the process can commence, several modifications to the dataset are required.

Transformation

Fortunately, the cover data in the vegetation assessment was of ordinal type and can be placed in rank order (Kent 2012; Wildi 2013), though this scale is not purely numeric (Peet & Roberts 2012). Cover values do not truly represent the actual cover by individual species (Dale 1989; Wildi 2013). For example, a species with a cover value of 2 has a five-fold cover range of 1 to 5%, whereas a species with a cover value of 4 has a two-fold cover range of 25 to 50%, a highly disproportionate increase of the cover range. To overcome this a transformation of the data that improves its numerical properties is recommended (Dale 1989; Peet & Roberts 2012). Wildi (2013), recommends that the x values be transformed by choosing an appropriate value for y that will reflect either the qualitative or quantitative approach to the data (Table 3.6, following page). The choice of $x^{2.5}$ can be seen to approximate the average cover percentages, however, there is some reluctance in using high percentages due to errors in visually assessing cover (Wildi 2013). He believes that this reluctance is not warranted, as using "coarse rank" scales such as Braun-Blanquet do not lead to reduced observation errors (Wildi 2013, p. 34).

Table 3.6: Options for the transformation of cover-abundance values. **Source:** Wildi (2013).

Modified cover code	Cover range	Cover amount	Average cover %	$x^{0.1}$	$x^{0.25}$	$x^{2.5}$ (cover)
0	not present	NA	0	0	0	0
1	<1%	<1	<1	1	1	1
2	1-5%	4	3	1.07	1.19	5.65
3	5-25%	20	15	1.12	1.31	15.58
4	25-50%	25	37.5	1.15	1.41	32
5	50-75%	25	62.5	1.17	1.50	55.9
6	>75%	25	87.5	1.19	1.57	88.18

Care has to be taken so that any transformation does not up-weigh species that display low cover (cover value 1, 2 and 3) at the expense of those species that display high cover (cover value 4, 5 and 6) (Peet & Roberts 2012). If this occurs, single species sites (e.g. *Sarcocornia* lawns – 100% cover, a value of 6) are arbitrarily lost when compared to the incidence of a single species that has a low cover of just 25% (cover value 3), for example, based on the $x^{0.1}$ scale 1.12 (cover value 3) versus 1.19 (cover value 6). Use of the "average cover" scale (%) in Table 3.6 is more equitable, as in the case outlined above, treats a single species site more appropriately – 1.19 ($x^{0.1}$) and 1.57 ($x^{0.25}$) versus 87.5. This process highlights the differences between the low and high cover values suggesting that a transformation should be carried out (Peet & Roberts 2012). Cover abundance data were transformed to "average cover".

Standardisation

Standardisation or scaling of data is required to compare data that uses different scaled measurements (Wildi 2013), such as moisture range of 0 to 100%, and pH range of 0 to 14. However, as the vegetation data was used as stand-alone, no standardisation of the cover data was required. Nonetheless, when it came time to review the cover data against the environmental/soil characteristics (moisture, pH etc.), the dataset will have to be standardised (see Chapter 4).

Clustering methods

For some ecological applications it may be adequate to differentiate groups without considering hierarchy. However, the hierarchical approach provides the advantage that similarity between groups is accounted for. This permits the adjustment of the number of groups/clusters by simply adjusting the hierarchical "cut-off" level (Wildi 2013, p. 56). A number of hierarchical agglomerative methods have been used in vegetation

ecology, for example: a) single linkage, b) complete linkage, c) average linkage, d) minimum-variance (often referred to as Ward, and from herein), and e) Flexible β (Aho *et al.* 2008; Kent 2012; Peet & Roberts 2012; Wildi 2013).

Single linkage is very prone to chaining where new vegetation plots are simply added to one large cluster and several clusters can also be formed from single plots (Aho *et al.* 2008), thus this method has little contemporary use in vegetation analysis (Peet & Roberts 2012). Complete linkage emphasises maximum rather than minimum dissimilarities and can lead to many equal sized clusters as the algorithms operate at plot level, not cluster level (Williams *et al.* 1966). Average linkage uses the average dissimilarity of each plot in the cluster to all other plots in another cluster, operating between single and complete linkages, thus this method forms irregularly shaped clusters and is less prone to chaining (Peet & Roberts 2012). The Average linkage method possesses a space conserving strategy that does not allow for reversals and it disregards group size dependence. Minimum-variance clustering (Ward 1963) method, often referred to as sum of squares clustering (Orloci 1967), combines plots in such a way that the within-group variance is minimised (Wildi 2013). There are two different algorithms found in the literature for the Ward method of clustering. One does not reflect Ward's clustering criterion, whereas the second, used in this current analysis, does (Murtagh & Legendre 2014). This method uses the Euclidean distance matrix (Peet & Roberts 2012) and can differentiate groups of differing size, shape and density, that is distinguishing groups that have low internal variance from those that have high difference (Wildi 2013). Ward's method has a similar space conserving strategy to that of the Average linkage method, however, rather than minimising an average distance, this method minimizes a squared distance weighted by cluster size (Kent 2012). A good compromise between average linkage and complete linkage is a hierarchical agglomerative method commonly known as Flexible β, (Lance & Williams 1967). Flexible β is "flexible" as it allows the analyst to control the space distorting properties (Kent 2012) by assigning a value to β; with a β value of negative 0.5, the method approximates Ward's method, thus providing an alternate to the Euclidean distance matrix, the use of which concerns some researchers (Peet & Roberts 2012).

A study by Aho *et al.* (2008), comparing two global datasets using five hierarchical agglomerative methods, determined that Flexible β, Average linkage and Ward's

method achieved the best results. These three methods were used in the analysis.

Distance matrix (resemblance/comparison measures)

Resemblance measures are those methods that focus on the joint occurrence of plots or species (Wildi 2013) and calculate a matrix of similarity/dissimilarity either between plots or between species (Lepš & Šmilauer 2003). The similarity of plots involves the similarity of plants species composition, whereas the similarity of species describes the pattern of distribution of species among the plots (Clarke & Warwick 2001; Lepš & Šmilauer 2003). Conversely, dissimilarity measures are those that measure to what degree plots are different in vegetation composition (Kent 2012).

Vegetation datasets are multivariate because they contain many species over many plots. Therefore, there are numerous methods in defining similarity, each method providing different characteristics within the vegetation community (Clarke & Warwick 2001). For example, some similarity coefficients may focus on similarity of abundance of a few very common species, whereas others may focus on the presence of less common or rarer species (Clarke & Warwick 2001). Datasets can be presented in two ways:

- Absolute, fully quantitative data for each species, for example, presence and abundance (or cover); and
- Reduced, a simple measure of presence/absence (qualitative data) of each species (Clarke & Warwick 2001). NB absolute datasets can be converted to a reduced (binary) dataset.

In the case of absolute measure, two plots can only be classified as being perfectly similar if they hold the same species in exactly the same abundance, whereas in the case of reduced measure, two plots can be classed as being similar when the species combination is identical irrespective of the abundance of each species (Clarke & Warwick 2001). Similarity coefficients *(S)* generally define a range, either 0 to 1, or 0 to 100%, with the ends of the range expressing the extreme possibilities:

- $S = 0$ when two plots are totally dissimilar; or
- $S = 1$ (or 100%) when two plots are totally similar (Clarke & Warwick 2001; Kent 2012; Wildi 2013).

Similarity/dissimilarity measures on absolute (quantitative) data

Absolute data includes measures of abundance or cover. Large measures of abundance can often be particularly variable in replicate plots and it is not appropriate to base an assessment of similarity/dissimilarity of two plots based on a small quantity of very abundant species (Clarke & Warwick 2001). In this case, transformation of the data is necessary, as similarity/dissimilarity measures will perform better following transformation (see 3.3.2: Transformation – above). The significant differences in abundances can either be eliminated, or at best reduced, so that common and rare species contributions to abundance can be equalised (Kent 2012).

A number of similarity/dissimilarity measures can be used on quantitative data, these include: Bray-Curtis, Canberra, Sorensen, and Kulczynski coefficients (Clarke & Warwick 2001; Lepš & Šmilauer 2003; Kent 2012).

- Bray-Curtis: commonly used in ecology (Faith *et al.* 1987) and referred to as a balanced compromise (Clarke & Warwick 2001), performs well when data is transformed $\sqrt{y}$ or $\sqrt{\sqrt{y}}$ (4^{th} root). All species add something to the similarity measure, still retaining influence of the more common species as they are given a higher weighting than the less common (Clarke & Warwick 2001). The measure is unaffected by the inclusion or exclusion of species which are jointly absent from two plots (Clarke & Warwick 2001). Additionally, Bray-Curtis retains greater sensitivity as it is less prone to the influence of outliers (Grace & McCune 2002).
- Canberra: similar to the Bray-Curtis measure, however, the absolute differences in counts for each species are separately scaled, allowing an equal input from each species (Clarke & Warwick 2001). This can lead to an overcompensation by rarer species, which often have limited or no significance within the ecological community (Clarke & Warwick 2001).
- Sorensen: very similar to Bray-Curtis (Oksanen *et al.* 2013) and Jaccard (see below), however, when compared to Jaccard, common species have a "double weighting" (Wildi 2013). The measure ranges from 0 to 1 (see Jaccard - below), however, the coefficient of 50% = 0.667 (due to this method's double weighting). The resulting distance is semi-metric as the distance shape of three or more plots cannot be presented in Euclidean space, therefore application is somewhat

limited (Wildi 2013). As the Sorensen measure gives weight to common species (Kent 2012), it reduces the influence of rarer or less common species.

- Kulczynski: a close relative of the Bray-Curtis measure (see above), satisfies biologically motivated principles in relation to binary data, and is most effective and robust in monotonic and linear correlations (Faith *et al.* 1987).

Recommendations for similarity/dissimilarity measures: Bray-Curtis measure has played a dominant role (Clarke & Warwick 2001) in ecological studies and is one of the most effective measures (Grace & McCune 2002). It is strongly recommended by Faith *et al.* (1987) and Clarke and Warwick (2001) and satisfies most criteria for its use (Clarke & Warwick 2001). Kent (2012) recommends Sorensen, "…as it gives weight to the species that are common to both plots…" (Kent 2012, p. 117). Sorensen is also popular with Clarke and Warwick (2001) while Kulczynski is strongly endorsed by Faith *et al.* (1987), and Clarke and Warwick (2001).

Method selected in this study: Absolute (quantitative) data – Bray-Curtis.

Dissimilarity coefficients – a geometric approach

Dissimilarity coefficients, a degree in which two samples are dissimilar, is a concept that is the converse of similarity (Clarke & Warwick 2001). Principally used in ordinations, the dissimilarity between two plots is turned into a distance between plots as they appear in "space" (Wildi 2013, p. 39) or on a "map" (Clarke & Warwick 2001) (p. 2-8). Therefore, when the distance value is small – close to zero – it implies a close relationship, whereas a high value implies a greater distance between the two plots (Clarke & Warwick 2001; Kent 2012). Types of distance measures include: Euclidean, Manhattan, Chord (Figure 3.13), Canberra, and Bray-Curtis.

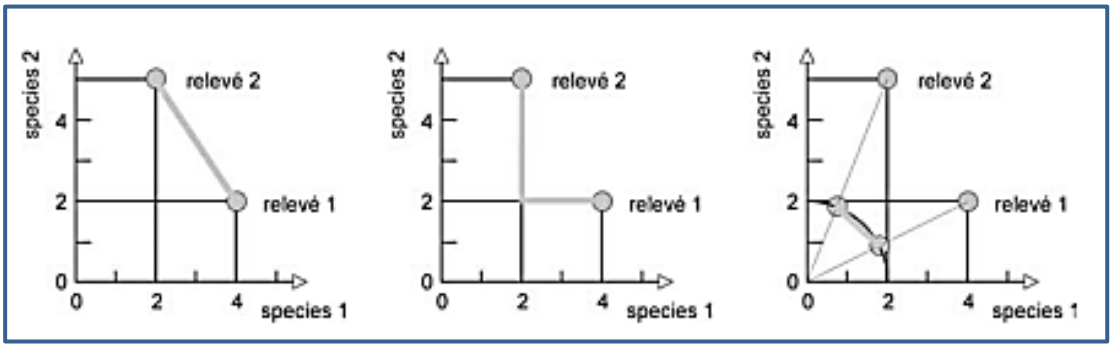


Figure 3.13: Three methods of measuring distance. **Left**: Euclidean; **Centre**: Manhattan; **Right**: Chord. **Source:** Wildi (2013).

- Euclidean (Figure 3.13): a straightforward, common measure (Lepš & Šmilauer 2003), it is the shortest distance in geometric space between two plots (Clarke & Warwick 2001; Wildi 2013), being the hypotenuse of the right-angled triangle formed between the two sample points (Kent 2012). If abundances of species present in the plots are low, Euclidean distance may also be low, which may be a drawback (Lepš & Šmilauer 2003). The measure ranges from the lowest value of zero (identical plots) to infinity (plots not identical in any way) (Wildi 2013). Care needs to be taken when comparing this measure against others that only range 0 to 1 (or 0 to 100%) as scales are different.

- Manhattan (Figure 3.13): a measure of the longest way, that is the sum of the distances of the right angle axes (Wildi 2013). This measure is similar to Euclidean and is useful when comparing species vectors (Wildi 2013). The range of measure (0 to ∞) for Manhattan is like that of Euclidean (see above). A point of note: both Euclidean and Manhattan are distances (or metrics) as both are measures of triangle space, whereas Bray-Curtis (see below) is a coefficient of dissimilarity, therefore non-metric (Clarke & Warwick 2001).
    - However, both Euclidean and Manhattan measures don't work so well when more species are involved (Wildi 2013), for example, if one plot had one species, yet the next had nine species – as is the case with the vegetation dataset being analysed.

- Chord (Figure 3.13): a measure of the "normalisation" (Wildi 2013, p. 40) or "standardisation" (Lepš & Šmilauer 2003, p. 83) of the Euclidean distance. It is a measure of the angle between the lines to each plot. Chord distance values range from 0 (totally identical plots) to 1.414213 (square root of 2) (non-identical plots in any way). This method is useful when investigating species composition (Lepš & Šmilauer 2003). However, as this method adjusts vector length only (normalisation) rather than both vector and variance (standardisation), it is not preferred by most users (Wildi 2013).

- Canberra: is a variant of Manhattan distance, where weights are determined by species scores involved. As a result, species with small scores (low abundance) get greater weight than when measured by Euclidean, a feature many users favour (Wildi 2013).

- Bray Curtis: a measure outlined above. It is often used in ordinations (e.g. nMDS), where the method has to force the similarity array into a graphic which is metric (Wildi 2013).

Recommendations for dissimilarity coefficients: Bray-Curtis, is popular as it adjusts the sum of scores which can return desired outcomes (Wildi 2013), is strongly recommended by Clarke and Warwick (2001). It is a satisfactory coefficient for use on biological data once suitably transformed (Clarke & Warwick 2001). Euclidean distance is useful in cluster analysis particularly when it comes to species space (Clarke & Warwick 2001), however, along with Chord and Manhattan, is a less robust measure (Faith *et al.* 1987).

Method selected in this study: Dissimilarity coefficient – Bray-Curtis

Analysis process – clustering

To determine the appropriate coastal saltmarsh vegetation communities for Tasmania, the following processes were implemented as follows:

- *Non-hierarchical:*
    - An obvious first option was to proceed with a k-means cluster of six groups as Tasmania has six coastal IBRA6.1 bioregions;
    - This was followed by a new round of k-means clustering to recommend a suitable number of clusters. Scree plots assisted in determining the number of clusters that were possible from the dataset; and
    - CascadeKM analysis and production of a cascade type plot to suggest number of clusters.
- *Hierarchical:*
    - Transformation of collected data (from Table 3.6 above):
        - Average cover (as this best represents actual cover and has similar values to $x^{2.5}$).
    - Distance matrix (following recommendations and initial analysis – see above):
        - Bray-Curtis measure.

- Clustering:
  - Average linkage;
  - Minimum-variance (Ward's); and
  - Flexible β (Lance & Williams 1967) with a β = - 0.5.

  Therefore, each cluster method incorporated the modified cover code transformed to average cover (see Table 3.6 above) along with the Bray-Curtis dissimilarity measure. This resulted in three outputs as dendrograms with associated data outputs.
- The results were evaluated for:
  - Agglomerative coefficient (AC) – a measure of how much clustering structure exists in the data; a high AC (close to 1) indicates that on average, objects that are merged within clusters are done so at the beginning of the algorithm, however, the closing merger is between distant clusters. A low AC indicates that the data is more evenly spread, an indication of a poor clustering structure that is not favoured in this study as an even spread is not a true representation of the plots.
  - Silhouette widths – a method to determine if group memberships are appropriate (Borcard *et al.* 2011). Here, the silhouette width, which is the measure of the degree of affiliation of the plot to its assigned cluster, is like that of its neighbours within that cluster. Widths can range from -1 (probably in the incorrect cluster) to 0 (a poor fit) to 1 (an excellent fit) and are averaged over the cluster (Borcard *et al.* 2011). The silhouette chart provides a graphical representation of the suitability of plot membership to the cluster.

Dendrograms

Hierarchical clustering methods generate a dendrogram, a diagrammatic depiction of the sequential meld of the plots into clusters, aggregated from bottom up (Peet & Roberts 2012). The dendrogram displays the different levels of similarity/dissimilarity very clearly, the differing levels being helpful in understanding vegetation community

patterns and aids interpretation (Kent 2012). The choice of cut-level, the position at which a line is drawn through the dendrogram to determine the final number of groups representing vegetation communities, can be subjective (Kent 2012), or natural breaks can occur which can aid decision making (Peet & Roberts 2012). Generally, a cut-level should be based on the intention of the classification, a decision sometimes independent to the data used in producing the clustering results (Wildi 2013). The cut level is often determined by experience and ecological knowledge of the analyst with phytosociological sense prevailing "…the best method should be the one that makes the most ecological sense" (my emphasis) (Kent 2012, p. 338).

Grouping

Scree plots from k-means clustering (twenty times) suggested that an appropriate number of groups (or clusters) was between seven and 10 with the most consistent number being eight. Each dendrogram was cut at levels seven, eight and nine and reviewed for principal species domination. This was followed by an examination of the make-up each individual vegetation community complex within each group, and to see if each individual group made "ecological sense" (Kent 2012, p. 338) as stand-alone followed by an overall appraisal of all vegetation communities as they fit within the coastal saltmarsh landscape consistent with observations in the field.

3.3.3 Ordination

The term ordination refers to an arrangement in any number of dimensions – preferably few in number – of vegetation plots based on relationships such as species similarity (Digby & Kempton 1987; Kent 2012). Ordination methods are often used in exploratory analysis that allows for summarising trends and examination of interrelationships between variables (Olden 2014). Generally, an ordination is presented in a graphical form where the dimensions have been compressed to form a 2D figure that allows for the examination of patterns that may exist in the vegetation dataset (Wildi 2013). Two methods of ordination are explored here: a) principal components analysis (PCA); and b) non-metric multidimensional scaling (nMDS).

Principal components analysis (PCA)

PCA is a data simplification technique designed to strip out correlations between variables. The method reduces data for easier management, for example, reducing say

ten variables to three that co-vary with the two others focusing on trended variations at the same time as suppressing "chatter" (Olden 2014). The method is relatively complex and is generally only used on short linear response gradients (Lepš & Šmilauer 2003) as results can suffer from distortions (Kent 2012). Although the use of this method is now a contentious issue, it is still regarded as being of fundamental importance (Clarke & Warwick 2001) as it has been extensively used on vegetation data for many years, and there are many instances of its use in literature (Kent 2012). The results of a PCA are repeatable – even when used in differing software programs (Wildi 2013). Clarke and Warwick (2001) suggest the exclusion of less common species as they can have a strong distorting impact on PCA ordination, and the omission of the rare species will have little impact on the final interpretation of the results. The greater benefit of PCA is its ability to merge environmental attributes and produce plot ordinations based on environmental values alone (Clarke & Warwick 2001; Kent 2012). This option will be addressed later when environmental and abiotic elements are introduced into the analysis of the data (see Chapter 4).

The basis of a PCA is eigenvectors and eigenvalues. Eigenvectors are scores that represent the weight of each of the species on each component. They range in value from -1.0 to +1.0, the higher or lower the score – that is closer to the extremes of the range – the greater the importance of the individual to the weight of the component (Kent 2012). Eigenvalues are the values that denote the contribution of each component to the total variation within the dataset (Kent 2012). The results of a PCA are displayed in a graphical plot having two axes. Individual pairs of axes can be displayed, e.g. PC1 and PC2, PC1 and PC3, PC2 and PC3 and so on. The principal axes are ranked in numerical order with PC1 having the highest weighting, followed by PC2, PC3 etc. Typical outputs from a PCA include:

- Eigenvalues of first 10 components;
- Scree plot (with a "broken stick") displaying the eigenvalue of each component and demonstrating the importance of each component; and
- A PCA ordination plot.

Non-metric multidimensional scaling (nMDS)

An nMDS ordination has been promoted as the best method of indirect ordination (Clarke & Warwick 2001; Kent 2012) and its use has increased over recent years. Its purpose is to build a map of plots in an identified number of dimensions endeavouring to fulfil conditions imposed by the rank similarity/dissimilarity matrix (Clarke & Warwick 2001). The method uses a rank order of distances, the relationship between ordination and variable space, and the minimal stress function (Olden 2014).
Clarke and Warwick (2001) suggest that there is little necessity to remove rare or less common species as the similarity measure used will generally down-weight rare species, and the number of plots will determine the computational scale (Clarke & Warwick 2001).

The goodness of fit measure of an nMDS is stress, the lower the value the better. It is recommended that multiple starts are made in nMDS as different results occur (Kent 2012) and that the lowest be retained (Roberts 2015). Stress value of <0.05 is considered excellent, it being a good representation with no likelihood of misinterpretation (Clarke & Warwick 2001), while <0.20 is considered to be satisfactory. The use of scree plots will assist in determining the number of dimensions or where the plot levels off, this level being the appropriate stress value (Kent 2012).
Typical outputs from an nMDS include:

- An nMDS ordination plot;
- Stress value; and
- A scree chart.

Furthermore, other data (such as climatic – see below) can be fitted to an nMDS ordination to explore potential "drivers" that have correlations to either plant species or plots.

Analysis process – ordination

To examine trends and interrelationships between variables, the following processes were implemented:

- *PCA:*
    - Transformation of collected data –

        - Remove rare and less common species; and
        - Use average cover for the remaining cover values.
    - Create a scree chart;
    - Produce charts comparing pairs of coordinates determined by the scree analysis; and
    - Fit a PCA ordination with groups specified from clustering.
- *nMDS:*
    - Transformation of collected data –
        - Average cover for all cover values.
    - Allow 20 iterations to determine a sequence of least stress;
    - Create and examine a Shepard (stress) chart;
    - Tabulate significant plant species;
    - Produce a plot-based nMDS ordination fitted with plant species at $p<0.01$;
    - Fit the above plot with climate data and investigate plant species and climate relationships (see below – Section 3.3.4);
    - Create a species-based nMDS ordination and fit with climate data (see below – Section 3.3.4); and
    - Fit an nMDS ordination with groups specified from clustering and investigate climate relationships.

3.3.4 Climatic variables

Selected rainfall, temperature and solar exposure data from each weather observation station (see Appendix 3A.1), were entered to a spreadsheet and matched to each vegetation community by use of function `envfit` in package `vegan` (Oksanen *et al.* 2013). Prior to analysis, both datasets (vegetation and climate) were standardised as temperature, rainfall and vegetation data used different scaled measurements. Outputs from fitting climate variables to an ordination include:

- Ordination between climate variables and plots; and

- Ordination between climate variables and vegetation communities.

Climate data were aligned to each of the groups formulated from the vegetation data. Once associated to each group, the group climate data were analysed using multivariate methods in the `vegan` package in R to:

- Examine the attributes of each group by use of boxplots summarising the quartiles; and
- Check for differences of group means using analysis of variance (ANOVA). A post hoc test, Tukey's Honestly Significant Difference (HSD) test, was used to identify those groups that differ significantly from each other.

3.3.5 Group indicator species

Individual plant species[31,32] can be chosen as indicators when they reflect the biotic state of the environment and their presence can predict the diversity of communities within an area. Indicator species emerge through an analysis of occurrence or abundance values from a set of sampled sites and the classification of the same sites into site groups, which may represent vegetation communities.

In this study, a single dataset was used to cluster the stations into group sites, and then to determine the indicator species within those groups. The site classification vector was determined using all cover values transformed to average cover; subsequently, the species indicator analysis used the same transformed cover values. The indicator species analysis was carried out in the R package `indicspecies` using the index "IndVal" devised by Dufrene and Legendre (1997). This is a measure of the association between a species and a group (of sites). The function used in package is `multipatt`, which searches for indicator species for individual sites and combinations of sites. The result from this analysis is a list of species that are significantly ($p<0.05$) associated with each group in decreasing indicator order. The list includes the indicator value components – A and B – the indicator value index being product of the two components (Dufrene & Legendre 1997; De Cáceres & Legendre 2009). Here, component A is the probability that the plot belongs to the site group assuming that the species has been found – a

[31] Follows: De Cáceres (2013)
[32] Follows: De Cáceres *et al.* (2010)

conditional probability called the "positive predictive value" of the species as an indicator of that specific site group. Component B is the probability of recording the species in plots belonging to the site group – a conditional probability called the "sensitivity" of that species as an indicator of the site group. For example, if species "X" in group 1 records component A as 1.0000, and component B as 0.8235, it is classed as a good indicator for group 1, although not all plots within group 1 record "X" as present. Again, if species "Y" in group 2 records component A as 0.8325, and component B as 1.0000, species "Y" can be used to indicate group 2 as it appears in all plots within this group (component B), and is largely, however, although not completely, restricted to it (component A).

3.3.6 Natural regionalisations and vegetation communities

The dataset was sorted in MS Excel by regionalisation and region to determine plot presence by region. Following analysis, the dataset was again sorted by regionalisation and region to determine vegetation community type existence by region.

Indicator vegetation communities

Individual vegetation communities were aligned to the individual regions of natural regionalisations. An indicator species (term used to represent vegetation communities) analysis was carried out in a similar fashion to that of group indicator species outline above (Section 3.3.5). The result from this analysis is a list of vegetation communities that are significantly ($p<0.05$) associated with each region in decreasing indicator order.

3.4 Results and Discussion

The following section incorporates a combination of both results and discussion because some results require examination prior to moving to the subsequent result. Within the following text, rainfall is expressed as mm (millimetres), temperature as ^{o}C (degrees centigrade), and solar exposure as MJ/m^2 (megajoules per square metre). All means are reported to standard error. **Note:** The term range, which is used to describe the minimum and maximum values (the limits) of an observation (e.g. rainfall 600 to 850, or temperature 14.3 to 21.4), and the term spread, used to describe the difference between the limits (the extent) of an observation (e.g. from above, 250 or 7.1) are presented as, for example, rainfall 600-850, 250, or temperature 14.3-21.4, 7.1. Results have been comprehensively reported.

3.4.1 Data screening

The following results and discussion refer to Phase 1 – Training sites (n = 21, containing 110 plots) data.

Species occurrence and cover

Species occurrence in number of plots, and mean cover in number of plots present are displayed as a histogram in Figure 3.14 and in Table 3.7.

The histogram demonstrates the species numbers per plot is heavily weighted to low numbers with one to ten species appearing in the greatest number of plots.

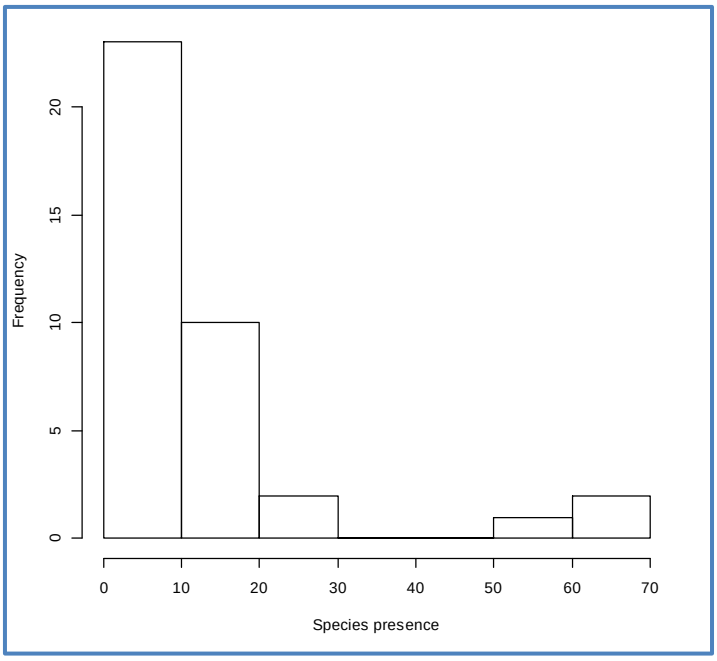


Figure 3.14: Training sites – histogram of species presence by frequency.

Table 3.7: Individual species, occurrence in Training sites by number and percent of plots, and mean cover exhibited by each species – order is based on presence, followed by mean cover. Full botanical names are provided.

Species (presence order)	Number of plots in which species occurs	Percentage of plots in which species occurs	Mean cover (%) over plots in which species occurs
Juncus kraussii	65	59.1	49.4
Sarcocornia quinqueflora	61	55.5	38.0
Samolus repens	51	46.4	21.5
Selliera radicans	25	22.7	15.2
Gahnia filum	21	19.1	25.8
Distichlis distichophylla	19	17.2	13.4
Apodasmia brownii	17	15.5	26.6
Suaeda australis	16	14.6	14.0
Tecticornia arbuscula	16	14.6	44.8

Species (presence order)	Number of plots in which species occurs	Percentage of plots in which species occurs	Mean cover (%) over plots in which species occurs
Austrostipa stipoides	13	11.8	43.7
Triglochin striata	13	11.8	3.5
Poa spp.	12	10.9	12.5
Sarcocornia blackiana	12	10.9	27.6
Atriplex paludosa	11	10.0	16.9
Disphyma crassifolium	11	10.0	16.9
Leptinella longipes	10	9.1	8.5
Isolepis cernua	7	6.4	4.4
Lawrencia spicata	7	6.4	19.4
Hemichroa pentandra	6	5.5	16.9
Ficinia nodosa	4	3.6	35.8
Wilsonia backhousei	4	3.6	43.8
Brachyscome graminea	3	2.7	18.5
Lilaeopsis polyantha	3	2.7	3.0
Schoenus nitens	3	2.7	15.0
Apium prostratum	2	1.8	20.3
Baumea juncea	2	1.8	20.3
Carpobrotus rossii	2	1.8	9.0
Leptinella reptans	2	1.8	15.0
Leptocarpus tenax	2	1.8	9.0
Lobelia irrigua	2	1.8	15.0
Poa labillardierei	2	1.8	26.3
Puccinellia stricta	2	1.8	0.5
Spergularia tasmanica	2	1.8	1.8
Atriplex cinerea	1	0.9	15.0
Lobelia alata	1	0.9	15.0
Lobelia anceps	1	0.9	3.0
Mimulus repens	1	0.9	3.0
Tetragonia implexicoma	1	0.9	3.0

The most dominant species (Table 3.7) documented during vegetation assessment was *J. kraussii* occurring in 59% (65) of plots, followed by *S. quinqueflora*, 55% (61) of plots, and *S. repens* 46% (51) of plots. These were the only species to occur in more than 40% of the plots. Three species, *Lobelia alata, Lobelia anceps* and *Mimulus repens* were the least dominant species, occurring in just one plot each with a mean cover of 3%. Species being least dominant in Training sites did not imply that they were rare, they just were not observed as often during the initial vegetation surveys.

Species richness

The species richness ranges from one to nine species per plot (per 4 square metres), with 17 (15%) plots housing a single species, 9 (8%) contain two, 22 (20%) contain 3 species, 21 (19%) contain 4 species, 14 (13%) contain 5 species, 15 (14%) contain 6 species, 9 (8%) contain 7 species, just two (2%) plots have 8 species, while just 1 (1%) contains 9 species. Total plant cover per plot ranges from just 37.5% to 150%, which may appear high. The low plant cover indicates plots with high bare ground cover (excluded from the data matrix), such as, LPPR1-3 and SCCA1-2, both having a very high percentage of bare ground. The high plant cover indicates two plots (DRLG2-3 and FLPCA1-3) have several vegetation layers thereby increasing total cover, for example, *T. arbuscula* with a cover score of 6 and *S. quinqueflora* (as ground cover under *T. arbuscula*) with a cover score of 5. This does occur in many of the study sites and is a common feature in sites that have multi-layering of plant species of differing structural forms.

Species average and mean cover

The average number of species per plot was 3.94. Mean species cover as a function of species presence is shown in Figure 3.15.

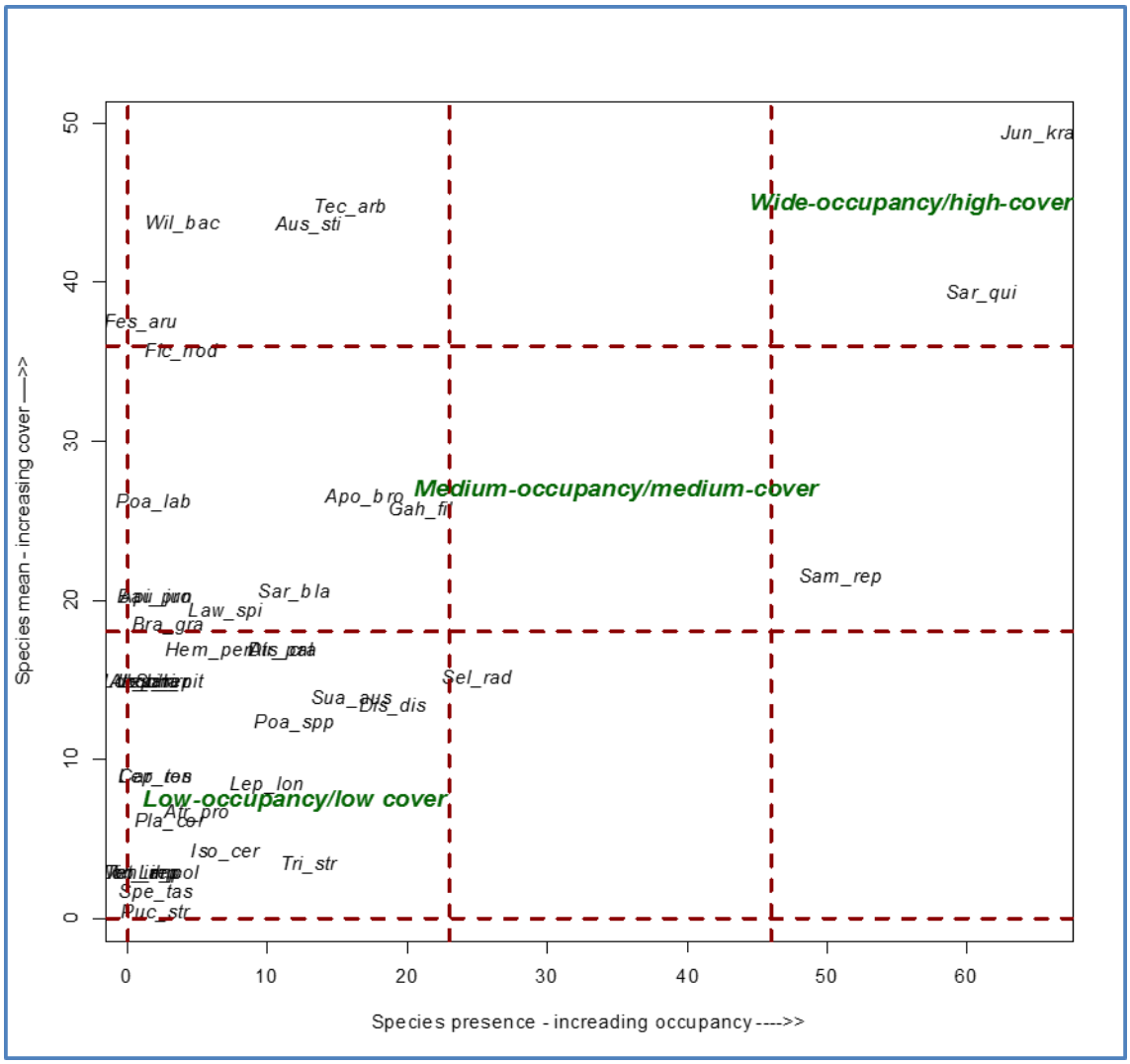


Figure 3.15: Species (by abbreviated name) presence as a function of species mean cover and occupancy based on Training sites data.

The most widespread species – *J. kraussii* (Jun_kra) – as well as having wide occupancy, also has the greatest cover, this followed by *S. quinqueflora* (Sar_qui). A species with medium spread, but still high in cover is *S. repens* (Sam_rep), with *S. radicans* (Sel_rad) close to medium range with a medium spread. Those species with low range, but with high cover include *T. arbuscula* (Tec_arb) and *A. stipoides* (Aus_sti) – both expected to have high cover as the former is a shrub and the latter a tussock grass. Species with a low range and a medium cover include *G. filum* (Gah_fil) and *S. blackiana* (Sar_bla), and those with low range and low cover include *Spergularia tasmanica* (Spe_tas) and *P. stricta* (Puc_str).

3.4.2 Classification and grouping

The following focuses on the clustering and grouping of data from Training sites only.

Non-hierarchical clustering

K-means

The initial process of k-means at six groups (representing the six coastal IBRA6.1 bioregions) proved unsatisfactory as distinction between groups was mediocre. The diversity within several suggested groups was too great, where some plots which displayed only two to three succulent species containing no graminoids were grouped with plots that contained saline graminoids with succulent plants as groundcover. Field inspection clearly showed that this would not be appropriate; furthermore, the prerequisite of being "a reasonable ecological fit" (Kent 2012, p. 338) within that respective group was not met, hence clustering at six groups using k-means was discontinued.

Results of the following round of k-means solutions are presented in Appendix 3A.2 (Figures 3A.2a to 3A.2h). It can be arbitrary when it comes to determining the elbow/kink in k-means scree plots, for example, a plot can display a kink at five as well as eight clusters, or four as well as six and eight clusters. However, with field knowledge to hand, four, five and six clusters would not be enough to adequately represent the real-life situation in the field.

The SSE plots indicated that eight was an appropriate number of clusters; it is acknowledged that a degree of bias has played a role in this interpretation as there were other possibilities, such as, four, five and six, however, such lower number of groups would not demonstrate "best ecological fit" (Kent 2012, p. 338). Subsequently, a further analysis of k-means results for eight groups provided the component information of group sizes as 10, 16, 14, 18, 18, 10, 17 and 7 plots. This was considered a suitable spread of plots over the eight groups.

CascadeKM

A cascadeKM analysis is displayed in Figure 3.16. This shows that an optimal grouping of plots is eight groups. Grouping of eight clusters is a good representation of the data, and furthermore, a reasonable ecological fit.

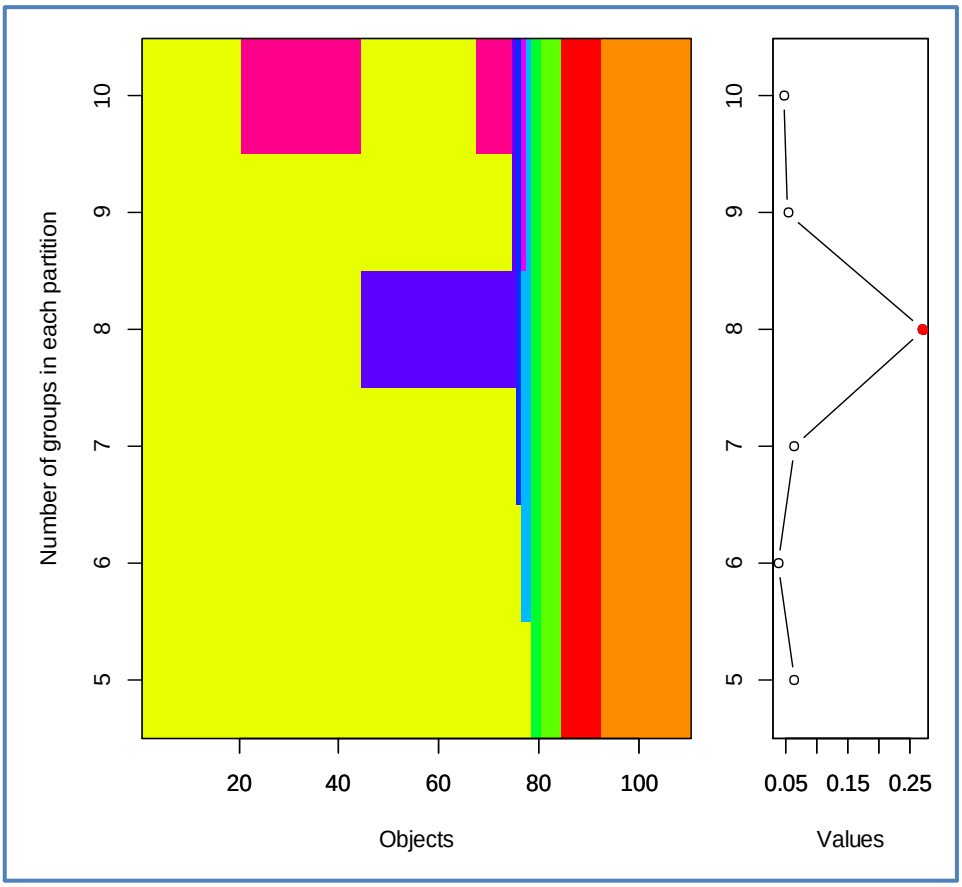


Figure 3.16: CascadeKM of vegetation cover/abundance of Training data. The left (coloured) plot shows the group attributed to each object for each partition; the right plot shows the values of the stopping criteria for different values of k (the number of groups). Here eight groups are recommended, with a no further option being offered.

Hierarchical clustering

Dendrograms

Dendrograms from hierarchical clustering are results are presented in Figures 3.17 to 3.19. Results from Flexible β (Figure 3.17) and Ward (Figure 3.18) cluster methods produced clusters that are a good fit both statistically and ecologically. Average linkage (Figure 3.19), however, returned groups that do not fit well with the field interpretation of the data and is not the "best ecological fit" (Kent 2012, p. 338).

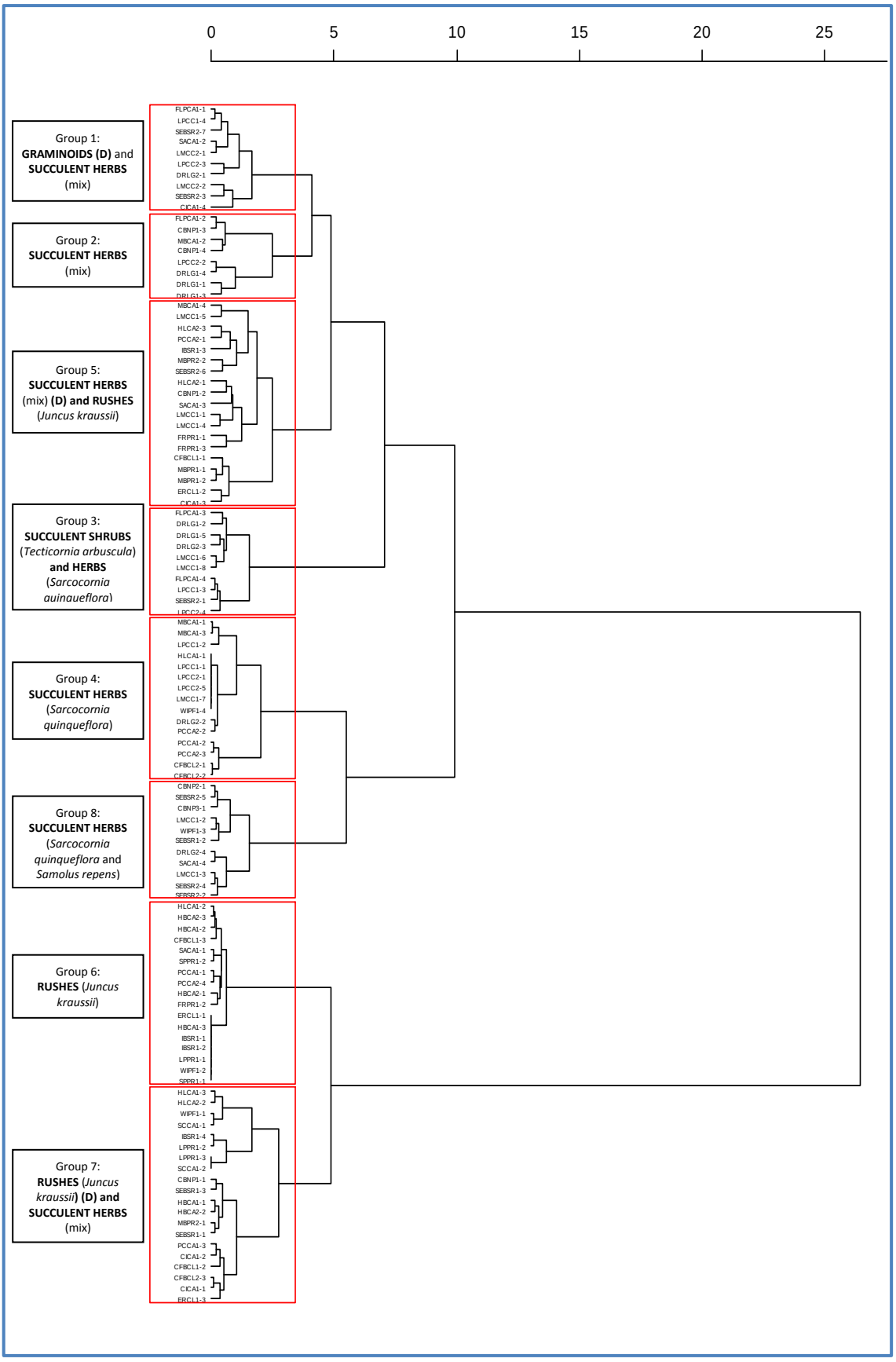


Figure 3.17: Dendrogram (of Training sites) generated from Flexible β clustering using Bray-Cutis dissimilarity measure. A call of eight groups "cut" the dendrogram at a level of 3.3 into satisfactory "field" representation and group sizes. Group sizes = 10, 8, 19, 10, 15, 11, 17 and 20. Each group has been identified as indicated on the left of the dendrogram.

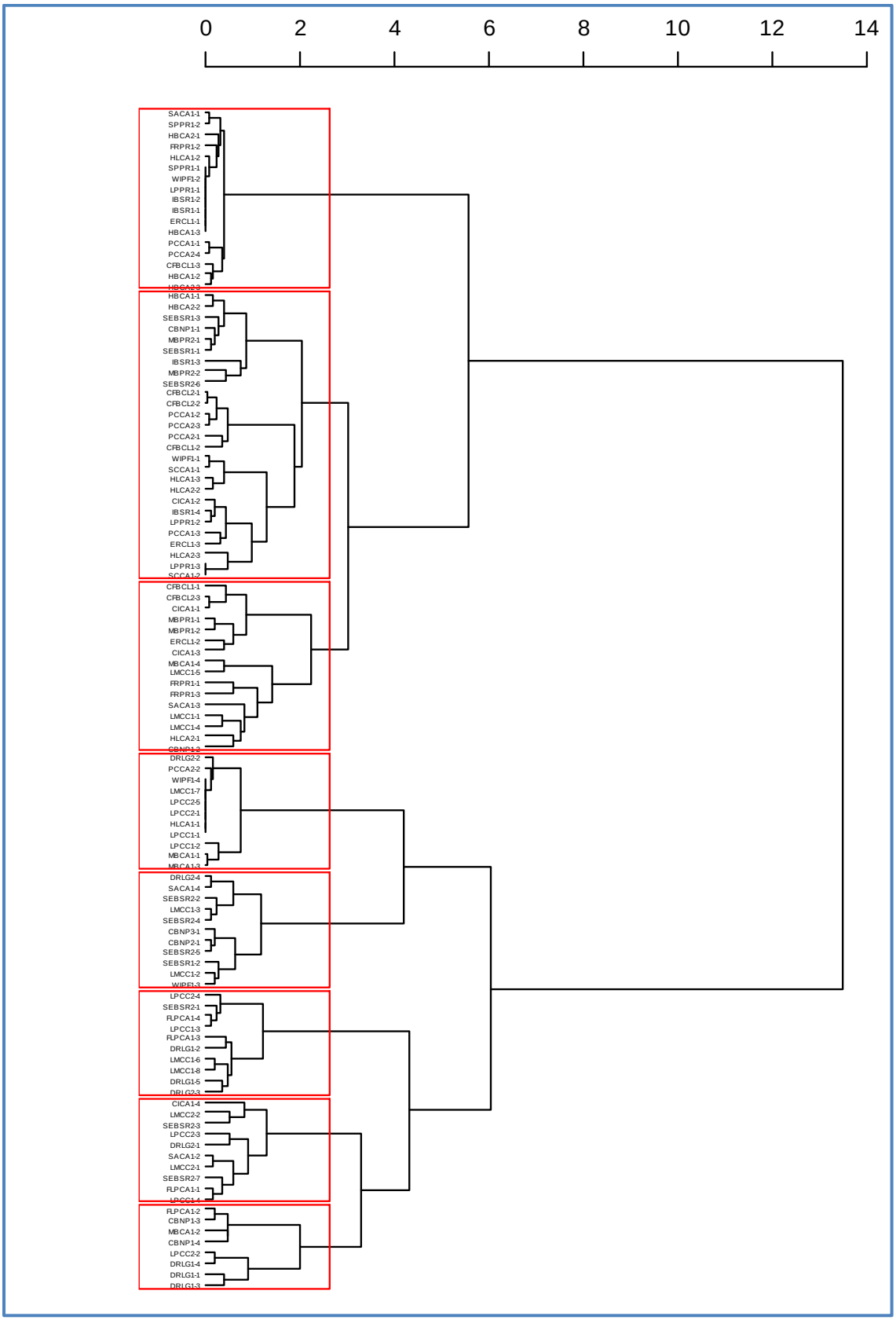


Figure 3.18: Dendrogram (of Training sites) generated from Ward clustering using Bray-Cutis dissimilarity measure. A call of eight groups "cut" the dendrogram at a level of 2.7 into a satisfactory "field" representation and group sizes. Group sizes = 17, 27, 16, 11, 11, 10, 10 and 8.

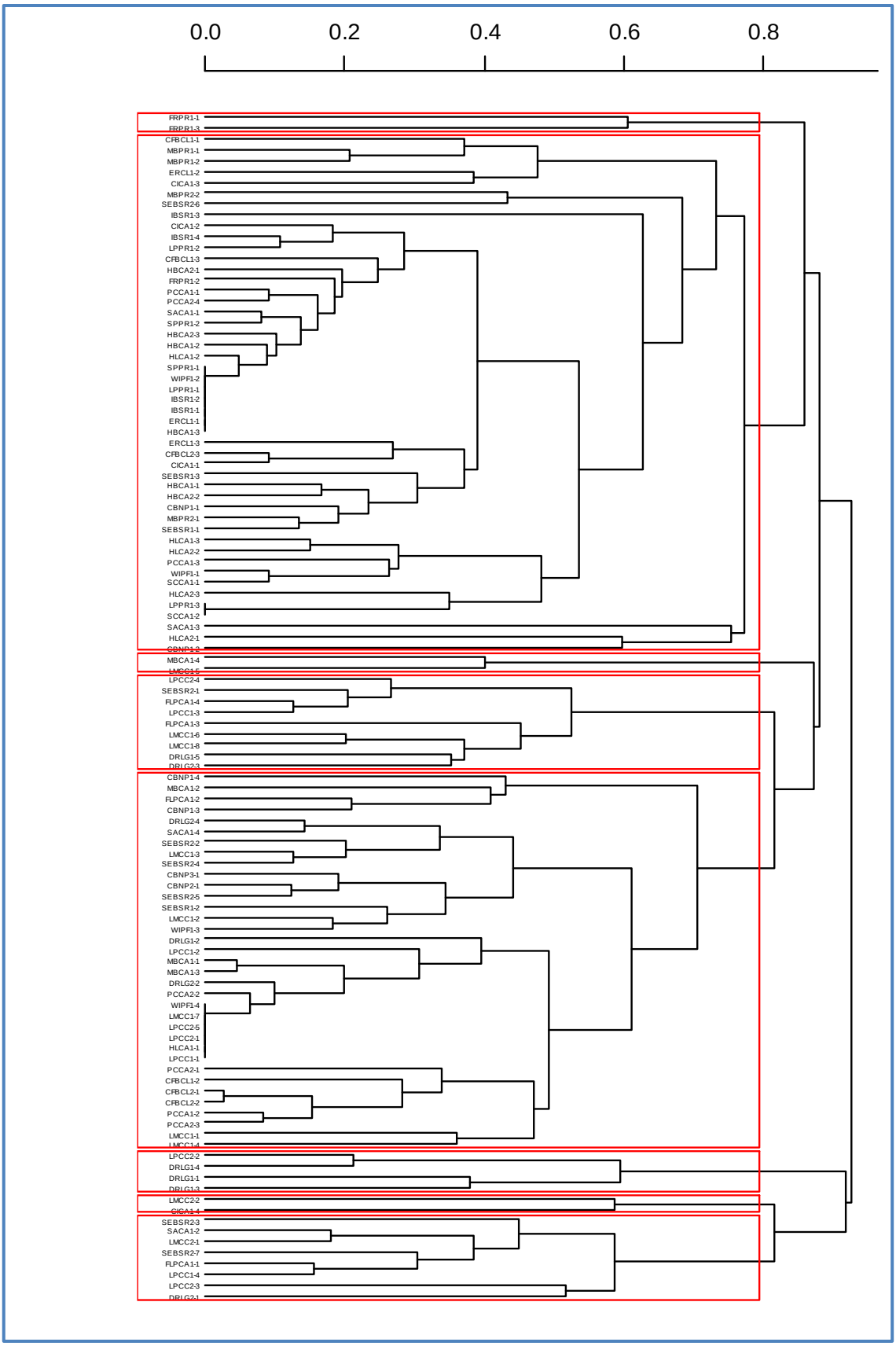


Figure 3.19: Dendrogram (of Training sites) generated from Average linkage clustering using Bray-Cutis dissimilarity measure. A call of eight groups "cut" the dendrogram at a level of 0.8 into a very unsatisfactory representation, in particular, group sizes. Group sizes = 2, 48, 2, 9, 35, 4, 2 and 8.

Of the three clustering methods, Flexible β returned the highest Agglomerative Coefficient (Table 3.8).

Table 3.8: Agglomerative coefficient per clustering method.

Cluster method	Agglomerative coefficient
Flexible β	0.991220
Ward	0.989339
Average Linkage	0.764428

Silhouette widths

Average silhouette width charts based on eight clusters are presented in Figure 3.20 (Flexible β), Figure 3.21 (Ward) and 3.22 (Average linkage).

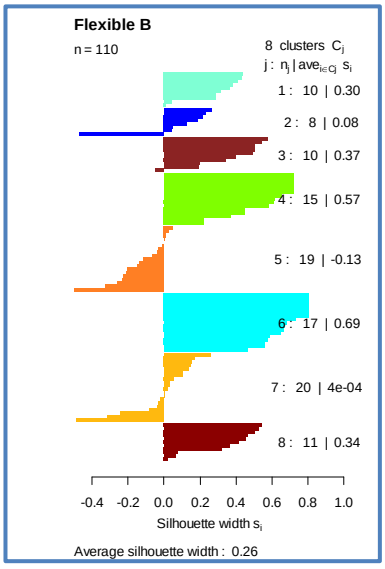


Figure 3.20: Flexible β silhouette chart, average silhouette width is 0.26, range from 0.0004 (very poor) to 0.69 (very good).

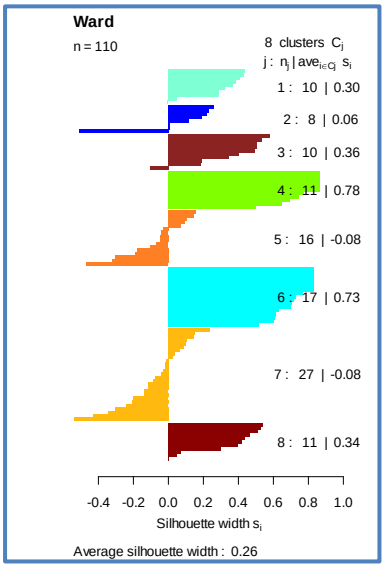


Figure 3.21: Ward silhouette plot, average silhouette width is 0.26, range from -0.08 (very poor) to 0.78 (very good).

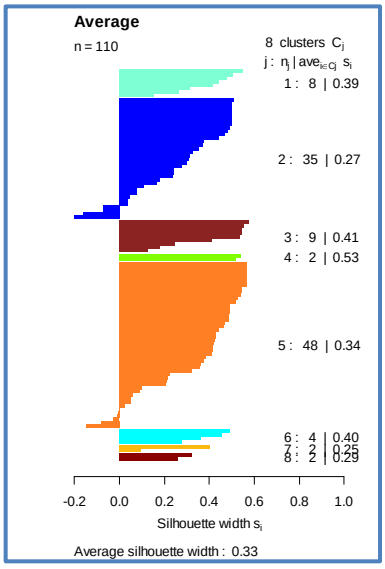


Figure 3.22: Average linkage silhouette plot, average silhouette width is 0.33, range from 0.25 (poor) to 0.53 (good).

J = group number, n_j = number of plots in group, ave_{iCj} S_i = average silhouette value for that group.

Average silhouette width (ASW) values can range from -1 (possibly in wrong cluster) to 0 (very poor) to 1 (excellent). Flexible β and Ward ASWs are 0.26, which is in the realms of being poor, whereas Average linkage is 0.33, not average, but better than either Flexible β or Ward – both at 0.26.

Silhouette charts for Flexible β and Ward have plots appearing on the left side indicating that four groups (in each) contain misclassified objects – outliers. In the case of Average linkage, just two groups contain outliers, hence a better ASW value.

However, three groups have just two members, and one has four. Furthermore, one group has 48 members with a low ASW of 0.34; another has 36 members, the ASW being 0.27. Although both Flexible β and Ward have poor overall ASWs, individual groups within each cluster method display high ASWs – Flexible β: 0.57 and 0.69, Ward: 0.78 and 0.73. Additionally, cluster structures for both Flexible β and Ward are acceptable, with Flexible β displaying 10, 8, 10, 15, 19, 17, 20 and 11 members, whereas Ward has 10, 8, 10, 11, 16, 17, 27 and 11 members.

The best method

However, it is not just the cluster sizes that should determine the best clustering method; clustering evaluations should also be considered (Table 3.9).

Table 3.9: Results of evaluations of each clustering method for 8 clusters.

Method	AC	ASW	Cluster sizes
Flexible β	0.991220	0.26	10, 8, 10, 15, 19, 17, 20, 11
Ward	0.989339	0.26	10, 8, 10, 11, 16, 17, 27, 11
Average Linkage	0.764428	0.33	8, 35, 9, 2, 48, 4, 2, 2

Method = cluster method; **AC** = agglomerative coefficient; **ASW** = average silhouette width.

Flexible β has the best agglomerative coefficient (clustering structure), closely followed by Ward, and then with a lower value, Average linkage. Both Flexible β and Ward have the same average silhouette width values (the appropriateness of group membership), with Average linkage being the best for ASW. If these measures are used as the basis for deciding the best clustering method, the decision would have to be between Flexible β and Average linkage. However, the suggested cluster sizes severely disadvantage Average linkage – three clusters with two members and another one cluster with four members – somewhat an inappropriate solution. The decision is then between Flexible β and Ward, both being very similar except for cluster sizes, where Flexible β appears to offer a better selection. However, are eight clusters the best option?

For the vegetation dataset, eight clusters were offered as the optimum number from k-means and cascadeKM non-hierarchical clustering methods, hence this value was used for evaluating hierarchical clustering of this dataset. As the results above do not appear to be completely satisfactory, further analyses were run on six, seven and nine clusters for each method (cluster numbers below six were deemed too small and would

not represent the "the best ecological state" (Kent 2012, p. 338), whereas cluster numbers greater than nine would be too unwieldy, especially for use in the field). The observed change following re-analysis is in average silhouette widths and the cluster sizes. The ASWs and cluster sizes for six to nine clusters are presented in Table 3.10.

Table 3.10: Clustering method, number of clusters, average silhouette widths and cluster sizes of vegetation data; methods highlighted in **GREEN** have the best average silhouette width values; numbers in **RED** (column – Cluster sizes) are deemed too low and unsuitable to form a cluster.

Method	No. of clusters	ASW	Cluster sizes
Flexible β	6	0.21	37, 10, 15, 17, 20, 11
Ward	6	0.21	18, 10, 11, 43, 17, 11
Average Linkage	6	0.29	21, 44, **2**, 48, **4**, **2**
Flexible β	7	0.24	18, 10, 15, 19, 17, 20, 11
Ward	7	0.24	10, 8, 10, 11, 43, 17, 11
Average Linkage	7	0.32	10, 35, 9, **2**, 48, **4**, **2**
Flexible β	8	0.26	10, 8, 10, 15, 19, 17, 20, 11
Ward	8	0.26	10, 8, 10, 11, 16, 17, 27, 11
Average Linkage	8	**0.33**	8, 35, 9, **2**, 48, **4**, **2**, **2**
Flexible β	9	**0.28**	10, 8, 10, 15, 19, 17, 8, 12, 11
Ward	9	**0.28**	10, 8, 10, 11, 9, 17, 27, 11, 7
Average Linkage	9	0.32	8, 35, 9, **2**, 45, **3**, **4**, **2**, **2**

ASW = average silhouette widths (for each cluster method/number of clusters).

This now confuses the situation – Flexible β and Ward are best at nine clusters each with ASW of 0.28, while, Average linkage best at eight with an ASW of 0.33. Ideally, Average linkage should be chosen at eight clusters, however, there are very low number of members in several clusters (2s and 4s) indicating that this is not a good practical solution. Even when the next highest ASW values are assessed, all are from Average linkage – 0.32 for both seven and nine clusters – the very low number of members in some groups remains at 2 and 4, again not the best practical results.

This then leaves the choice to be made between Flexible β and Ward, both being very similar except for cluster sizes (Table 3.11, following page).

Flexible β has the best median (13 compared to mean of 13.75) and standard deviation (4.59) for a cluster size of eight groups. The next best option, still with Flexible β at nine groups, has a median of 12.22 compared to mean of 11, with a low standard deviation of 3.93. As k-means and cascadeKM recommend eight clusters, Flexible β is selected as an appropriate method to cluster the vegetation data into eight clusters.

Table 3.11: Results of evaluations of Flexible β and Ward clustering methods on vegetation data.

Method	No clusters	ASW	Cluster sizes	Median	Mean	Std dev
Flexible β	6	0.21	37, 10, 15, 17, 20, 11	16	18.33	9.87
Ward	6	0.21	18, 10, 11, 43, 17, 11	14	18.33	12.55
Flexible β	7	0.24	18, 10, 15, 19, 17, 20, 11	17	15.71	3.90
Ward	7	0.24	10, 8, 10, 11, 43, 17, 11	11	15.71	12.35
Flexible β	8	0.26	10, 8, 10, 15, 19, 17, 20, 11	13	13.75	4.59
Ward	8	0.26	10, 8, 10, 11, 16, 17, 27, 11	11	13.75	6.18
Flexible β	9	0.28	10, 8, 10, 15, 19, 17, 8, 12, 11	11	12.22	3.93
Ward	9	0.28	10, 8, 10, 11, 9, 17, 27, 11, 7	10	12.22	6.22

ASW = average silhouette widths; **Std dev** = standard deviation

Grouping

A simplified code (with similarity to TASVEG) based on species composition within each vegetation community (wherever possible) was applied as follows:

- The three alphabetic code to begin with A (= aquatic) (Kitchener & Harris 2013);
- The following two letters (of the three-letter code) to reflect the description/ composition of each vegetation group (by species if possible) (Table 3.12).

Table 3.12: Phase 1 – draft vegetation community naming convention, plant species structure and description etc. ordered from low (adjacent to marine coast) to high marsh (adjacent to terrestrial vegetation).

Code	Naming convention	Name/Title	Description
ASQ	**S** = *Sarcocornia* **Q** = *quinqueflora*	Wet saltmarsh herbland 1	Succulent herb (*S. quinqueflora*)
AQR[1]	**Q** = *quinqueflora* **R** = *repens*	Wet saltmarsh herbland 2	Succulent herbs (*S. quinqueflora* and *S. repens*)
AHM	**H** = herbs **M** = mix (of species)	Wet saltmarsh herbland 3	Succulent herbs (mix)
AJK	**J** = *Juncus* **K** = *kraussii*	Rushland	Rushes (*J. kraussii*)
ARH	**R** = rushes (as dominant) **H** = herbs	Rushland and herbland	Rushes (D) and succulent herbs
ASH	**S** = shrubs **H** = herbs	Wet saltmarsh shrubland	Succulent shrubs and herbs
AHR	**H** = herbs (as dominant) **R** = rushes	Herbland and rushland	Succulent herbs (D) and rushes
AGH	**G** = graminoids (as dominant) **H** = herbs	Coastal tussock saltmarsh	Graminoids (D) and herbs

Note: D = dominant.

[1] Consideration was given to using code ASS, this to reflect *Sarcocornia* and *Samolus*, however ASS is already in use in TASVEG, therefore to maintain the distinction between both vegetation community codes (one broad scale, the other fine scale), AQR was used. This also maintains the hierarchical code of ASS as being the key identifier for succulent saltmarsh used at a broad scale.

Vegetation community key – Phase 1

A design structure was developed (Figure 3.23) and from this a draft (Phase 1) vegetation community key was designed (Table 3.13). The draft key was tested on a new round of coastal saltmarshes study sites – Test 1 in Phase 2.

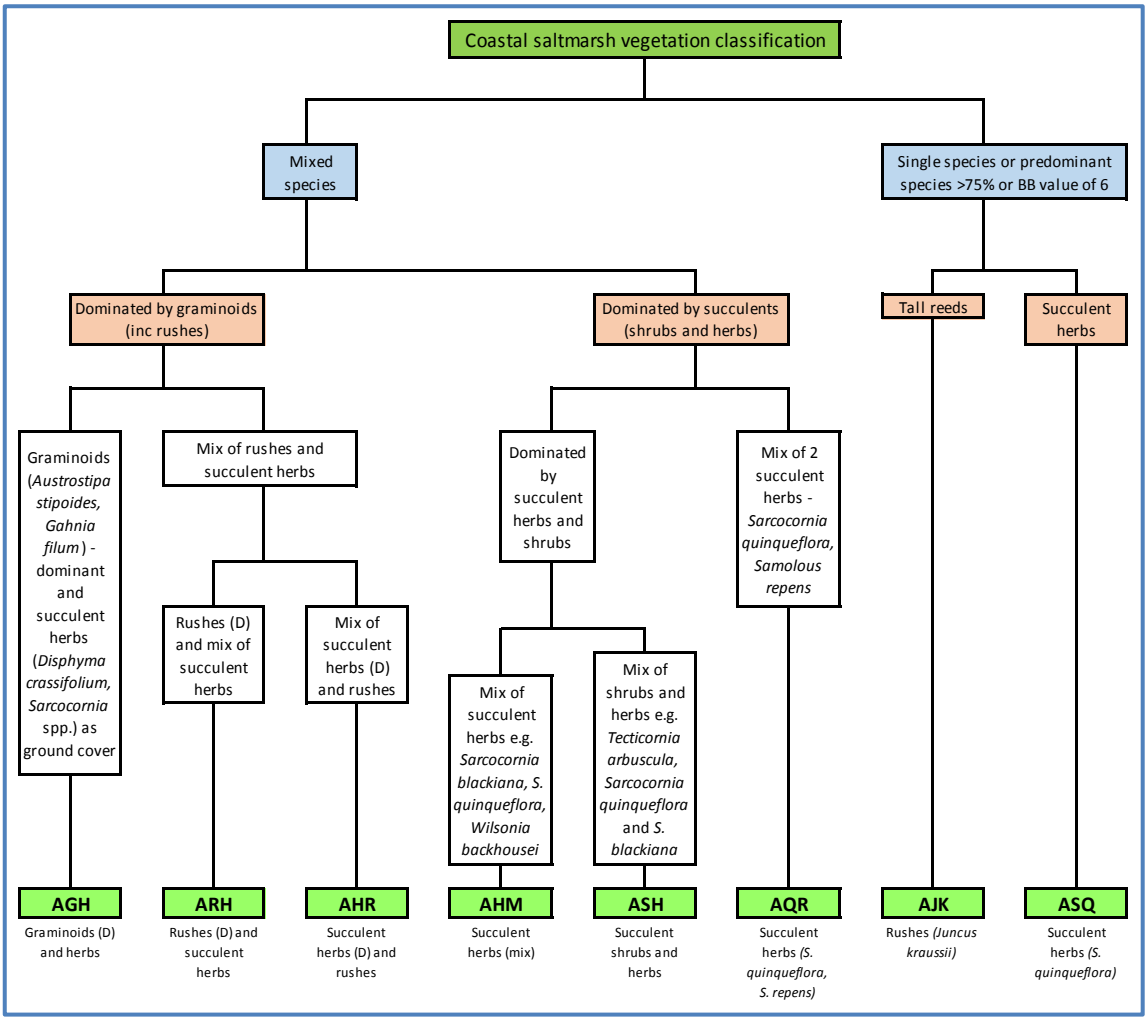


Figure 3.23: Design structure for a draft vegetation community key based on Training sites.
Note: (D) = dominant.

Table 3.13: Draft key for Tasmanian coastal saltmarsh vegetation communities.

A key to aid the identification and naming of vegetation communities of Tasmania coastal saltmarshes – draft key only (to test on new sites)

1. Is the vegetation community made up of a single species (e.g. *Juncus kraussii* or *Sarcocornia quinqueflora*)? ========== go to 2
   or
   multiple species? ========== go to 3

2. Does the community consist of reeds only? ======== **AJK (Rushes – *Juncus kraussii*)**
   or
   species of succulent herbs only? ========== ========== **ASQ (Succulent herbs – *Sarcocornia quinqueflora*)**

3. Is the vegetation community dominated by graminoids (including rushes)? = go to 4
   or
   dominated by succulents (shrubs and or herbs)? ========== go to 6

4. Is the vegetation community dominated by graminoids (e.g. *Austrostipa stipoides*, *Gahnia filum*) with succulent herbs (e.g. *Disphyma crassifolium*, *Sarcocornia* spp.) as ground covers? ========== **AGH – Graminoids (D) and Herbs**
   or
   a mix of rushes and succulent herbs? ========== go to 5

5. Is the vegetation community made up of rushes as dominant with succulents as ground cover? ========== **ARH – Rushes (*Juncus kraussii*) (D) and succulent Herbs**
   or
   is made up of succulent herbs as dominant with rushes ========== **AHR – succulent Herbs (D) (e.g. *Sarcocornia quinqueflora, Samolus repens*) and Rushes**

6. Does the vegetation community contain a mix of two succulent herbs species (*Sarcocornia quinqueflora* and *Samolus repens*) only? ========== ========== **AQR – succulent herbs *Sarcocornia quinqueflora* and *Samolus repens*)**
   or
   succulent shrubs and/or a mix of succulent herbs? ========== go to 7

7. Is the vegetation community made up of succulent shrubs and succulent herbs? ========== **ASH – succulent Shrubs (*Tecticornia arbuscula*) and Herbs**
   or
   a mix of three or more succulent herb species (e.g. *Disphyma crassifolium*, *Sarcocornia* spp., *Wilsonia backhousei*)? ========== **AHM – Succulent Herbs (Mix)**

3.4.3 Phase 2 – Testing the draft key

The vegetation community key prepared above was applied to Test 1 sites (n = 27) containing 138 plots.

Vegetation community codes

Twelve (9.4%) of the 128 Test 1 site plots could not be field-identified from the key, three (2.3%) of the remaining 116 plots were somewhat misidentified in the field. Therefore, the usability of the current key was accepted as being 88% reliable.

Besides plant species identification being an issue at the commencement of this study, visually assigning individual species dominance over remaining species (within each plot) and being prepared to add a degree of "flexibility" to the key's interpretation, were acknowledged as contributing factors to either being unable to assign a code to, or misidentifying, a vegetation community.

Unidentified communities

Applying the key to the unidentified communities at the desktop, identified several interpretation issues (Table 3.14).

From the table below, selecting an appropriate vegetation community code when a secondary species is not present, or in some cases when ground cover species (particularly succulent herbs) are absent in a plot, can thwart selection of a justifiable code for that plot.

Table 3.14: Individual Test 1 site plots, reason for being unidentified, suggested vegetation code and justification for that suggestion. Numerical value following species name is the cover abundance score for that species.

Plot ID	Unidentified vegetation communities – plant species comments	Suggested Code	Justification for this vegetation community code
HPPR2	Two species only – *Austrostipa stipoides* (5) and *Juncus kraussii* (3) – no herbs as groundcover.	AGH	Dominance of *A. stipoides* over *J. kraussii*, though acknowledged no ground cover species.
HPPR3	One species only – *Tecticornia arbuscula* – no groundcover species.	ASH	Succulent shrub code although acknowledged this plot lacks any ground cover species.
WHBCA6	Dominance of *Sarcocornia quinqueflora* (6) whereas *T. arbuscula* (2), is this community ASQ, ASH or AHM?	ASQ	Dominance of *S. quinqueflora* (6) whereas *T. arbuscula* has only a cover of 2
SCPF1	*J. kraussii* (5) and *Gahnia filum* (4), is it ARH or AGH?	ARH	Dominance of *J. kraussii* (5) over *G. filum* (4).

Plot ID	Unidentified vegetation communities – plant species comments	Suggested Code	Justification for this vegetation community code
SCPF6	*J. kraussii* (5), *A. stipoides* (3) and *G. filum* (3), is it ARH or AGH?	ARH	Dominance of *J. kraussii* (5 = 50-75%), whereas 3 = 5-25% cover (*A. stipoides* and *G. filum*).
ELPS7	Three graminoids species (*G. filum* 5, *A. stipoides* 3, *J. kraussii* 3), no ground cover species	AGH	Dominance of *G. filum* (5) along with *A. stipoides* (3).
RPCC6	Two herbs – *Samolus repens* (5) and *W. humilis* (2) with *T. arbuscula* (2), is it ASH or AHM?	AHM	Dominance of herbs (*S. repens* 5 and *Wilsonia humilis* 2) over *T. arbuscula* (3).
ABCA3	Four species of herbs (4, 3, 3, 3) with *Apodasmia brownii* (4) and *Poa* spp. (3), AGH or AHR?	AHR	Dominance of herbs, with rushes being non-dominant; note: *A. brownii* classified as a rush.
ABCA4	*G. filum* (6) with no ground cover species, is it AGH (though no herb ground cover exists)?	AGH	Dominance of *G. filum* though acknowledged as lacking ground cover species.
PRCL3	*G. filum* (5) with no ground cover species, is it AGH?	AGH	Dominance of *G. filum* though lacking ground cover species.
DRPR4	Three graminoids species (*G. filum* 4, *A. stipoides* 3, *J. kraussii* 4) with no ground cover species, is it AGH or ARH?	AGH	Dominance of *G. filum* (4) along with *A. stipoides* (3) outweighs *J. kraussii* (4), lacking in ground cover species.
PPCA3	*G. filum* (6) with very low ground species cover.	AGH	Dominance of *G. filum* (6).

Plot ID's: **HP** = Hildyards point, **WHB** = Watch House Bay, **SC** = Saltwater Creek, **EL** = Earlham Lagoon, **RP** = Railway Point, **AB** = Acton Bay, **PR** = Pipers River, **DR** = Detention River, **PP** = Pelican Point.

Misidentified vegetation communities

Misinterpreting structural form led to the vegetation communities in three plots being incorrectly identified (Table 3.15). Here, dominance of tall graminoid plant species was an important consideration in vegetation community identification.

Table 3.15: Individual Test 1 site plots, field ID, actual vegetation assessment, suggested vegetation code and justification. Numerical value following species name is the cover abundance score for that species.

Plot ID	Field ID	Vegetation assessment	Desktop ID	Justification for this vegetation community code
FCICA4	AHR	*Juncus kraussii* (5), *Sarcocornia quinqueflora* (4), *Distichlis distichophylla* (2).	ARH	Structural form of *J. kraussii* dominates (>50%) over ground cover.
PRCL4	AHR	*S. quinqueflora* (5), *J. kraussii* (4), *Apodasmia brownii* (3), *Selliera radicans* (3), *D. distichophylla* (2), *Poa* spp. (2).	ARH	Pooled *J. kraussii* and *A. brownii* total >50% cover, therefore these species dominate.
KRPR5	AHR	*J. kraussii* (5), *S. quinqueflora* (5), *S. radicans* (3).	ARH	Structural form of *J. kraussii* dominates (>50%) over ground cover.

Furthermore, understanding and appreciating the concept of "combining" individual plant species to a subgroup within the vegetation community is important. Plot ABCA3 (see Table 3.14) is a good example – here there are four species of herbs (one with a cover value 4, the other three, each recorded a cover value 3 – therefore a pooled mean cover of 82%), present as groundcover to two graminoid species (one recorded with a cover 4, the other a cover 3 – a pooled mean cover of 52%). It would be easy to visually classify this plot as AGH (graminoids as dominant with herbs as ground cover), yet, the subgroup of herbs is dominant over the graminoids, thus resulting in a classification of AHR (herbs as dominant over rushes – *A. brownii* is a rush). Note: with stratification and multiple layering, total cover values often exceeded 100%, a common occurrence using the Braun-Blanquet method.

Updated vegetation community key

The issues identified above, were considered in preparing the proposed (Phase 2) vegetation community key (Table 3.16), this for testing in coastal saltmarshes using a new round of study sites – Test 2 in Phase 3.

Table 3.16: Proposed vegetation community key for Tasmanian coastal saltmarsh vegetation communities. Clarifications made to describing dominance/dominant. To be field verified on Test 2 sites.

A key to aid the identification and naming of vegetation communities of Tasmania coastal saltmarshes – proposed key only (to test on next round of sites)

1. Is the vegetation community made up of a single species (e.g. *Juncus kraussii* or *Sarcocornia quinqueflora*)? ========== go to 2
   or
   multiple species? ========== go to 3

2. Does the community consist principally of reeds only, or a presence of other species with a cover value of 2 or less? ========== **AJK (Rushes – *Juncus kraussii*)**
   or
   consist principally of succulent herbs only, or a presence of other species with a cover value of 2 or less? ========== **ASQ (Succulent herbs – *Sarcocornia quinqueflora*)**

3. Is the vegetation community dominated by graminoids (including rushes)? ======= go to 4
   or
   dominated by succulents (shrubs and or herbs)? ========== go to 6

4. Is the vegetation community dominated by graminoids (e.g. *Austrostipa stipoides*, *Gahnia filum, Juncus kraussii*) with succulent herbs (e.g. *Disphyma crassifolium*, *Sarcocornia* spp.) as ground covers? ========== **AGH – Graminoids (D) and Herbs**
   or
   a mix of rushes and succulent herbs? ========== go to 5

5. Is the vegetation community made up of rushes as dominant (>50% cover) with succulents as ground cover? ========== **ARH – Rushes (*Juncus kraussii*) (D) and succulent Herbs**
   or
   is made up of succulent herbs as dominant (>50% cover) with rushes ========== **AHR– succulent Herbs (D) (e.g. *Sarcocornia quinqueflora*, *Samolus repens*) and Rushes**

6. Does the vegetation community contain a mix of two succulent herbs species (*Sarcocornia quinqueflora* and *Samolus repens*) only? ========== **AQR – succulent herbs (*Sarcocornia quinqueflora* and *Samolus repens*)**
   or
   succulent shrubs and/or a mix of succulent herbs? ========== go to 7

7. Is the vegetation community made up of succulent shrubs (>50% cover) and succulent herbs? ========== **ASH – succulent Shrubs (*Tecticornia arbuscula*) and Herbs**
   or
   a mix of three or more succulent herb species (e.g. *Disphyma crassifolium*, *Sarcocornia* spp., *Wilsonia backhousei*)? ========== **AHM – Succulent Herbs (Mix)**

3.4.4 Phase 3 – Testing the proposed key

The vegetation community key prepared above was applied to Test 2 sites (n = 43) containing a total of 169 plots.

Vegetation community codes

Ten (5.9%) of the 169 Test 2 sites plots could not be field-identified from the key, nine (5.3%) of the remaining 159 plots were somewhat misidentified in the field. Therefore, the usability of the current key was accepted as being 89% reliable.

Similar issues experienced during Test 1 assessments were also encountered during this round of assessments. This was generally due to a new range of sites visited, including those on the west and south coasts with new species documented – *Phragmites australis* and *Schoenoplectus pungens*. Being prepared to add a degree of flexibility to the key's interpretation was acknowledged as an underlying reason for either being unable to assign a code to, or misidentifying, a vegetation community. Hopefully, this has now been addressed because an improved understanding of coastal saltmarsh complexity has been gained by assessing a greater number of sites in somewhat more diverse locations.

Unidentified communities

Applying the key to the unidentified communities at the desktop, identified several interpretation issues (Table 3.17).

Selecting an appropriate vegetation community code when a secondary species is not present, or in some cases when ground cover species (particularly succulent herbs) are absent in a plot, can thwart selection of a justifiable code for that plot. A degree of flexibility needs to be incorporated to the vegetation community key to cater for plots that do not display groundcover herbs, yet the plot can be classified as graminoids or rushes due to the dominance of those species. To create extra classifications would make the key more cumbersome for field use and increase complexity which may lead to reduced acceptability by field workers.

Table 3.17: Individual Test 2 site plots, reason for being unidentified, suggested vegetation code and justification for that suggestion. Numerical value that follows species name is the cover abundance score of that species.

Plot ID	Unidentified vegetation communities – plant species comments	Suggested Code	Justification for this vegetation community code
LBCA5	Four species only – *Apodasmia brownii* (4) and *Austrostipa stipoides, Juncus kraussii* and *Poa* spp. (all 3) – no herbs as groundcover.	AGH	Technically all are graminoids, so use of AGH justified, though acknowledged no ground cover species.
LBCA6	Dominance of *J. kraussii* (5), with *A. stipoides* and *Poa* spp. (3) – no groundcover species.	AJK	Dominance of *J. kraussii*, other species may only be at 5% (a cover of 3 ranges 5% to 25%).
ABPR1	*J. kraussii* and *Phragmites australis* both 4	ARH	Technically rushes – therefore use the rush classification, acknowledged no herbs.
ABPR2	Dominance by *A. brownii* (5) and *P. australis* (2).	ARH	Technically rushes – therefore use the rush classification, acknowledged no herbs
ABPR4	Dominance by *A. brownii* (6), *J. kraussii* and *P. australis* both at 3.	ARH	Technically rushes (rushes only) – therefore use the rush classification, acknowledged no herbs.
CB1PF6	Dominance by *J. kraussii* and *Ficinia nodosa* both at 4, with *Poa labillardierei* also 4.	AGH	All graminoids (reeds and grasses) – therefore use the graminoid classification, acknowledged no herbs.
CB2PF2	Two species – *J. kraussii* (5) and *F. nodosa* (4).	AHM	Technically rushes (rushes only) – therefore use the rush classification, acknowledged no herbs.
CB2PF3	Dominance by *J. kraussii* (5) and *F. nodosa* and with *P. labillardierei* at 4.	AGH	All graminoids (reeds and grasses) – therefore use the graminoid classification, acknowledged no herbs
PRSR1	Dominated by *Schoenoplectus pungens* (6), with a mix of herbs.	ARH	A dominance of reeds *(S. pungens)*, with herbs.
PRSR2	Dominated by *S. pungens* (6), with a mix of herbs.	ARH	A dominance of reeds *(S. pungens)*, with herbs.

Plot ID's: **ABPR** = Adventure Bay, **CB1PF** and **CB2PF** = Cloudy Bay, **LBCA** = Luttrells Bay, **PRSR** = Pieman River.

Misidentified vegetation communities

Misinterpreting the dominance of individual species led to some vegetation communities being incorrectly identified. For example, two plots, one at Great Bay (GBCA3), the other at Bangor (BBRPF2) were field classified as AHR based on the presence of *J. kraussii* at a cover value 3, yet one herb (e.g. *H. pentandra*) was assessed at a cover of 5 with a mix of four other herbs (e.g. *S. quinqueflora, S. repens*) all at cover score of 3. During the desktop review of field classifications, it was apparent that these

are two examples that should have been classed as AHM (herbs mixed) as the *J. kraussii* displays very low cover (it may be just 5% as cover of 3 has a range of 5 to 25% – the cover may have been greater than 5%, however the number of herbs and their individual cover values suggest that AHM is an appropriate classification).

All issues identified above, were considered in preparing the final vegetation community key.

3.4.5 Combined data

The following focuses on Combined data, an aggregation of data from Training, Test 1 and Test 2 sites (n = 91, 407 plots).

Species occurrence and cover

Species occurrence in number of plots, and mean cover in number of plots present are displayed as a histogram in Figure 3.24 and in Table 3.18.

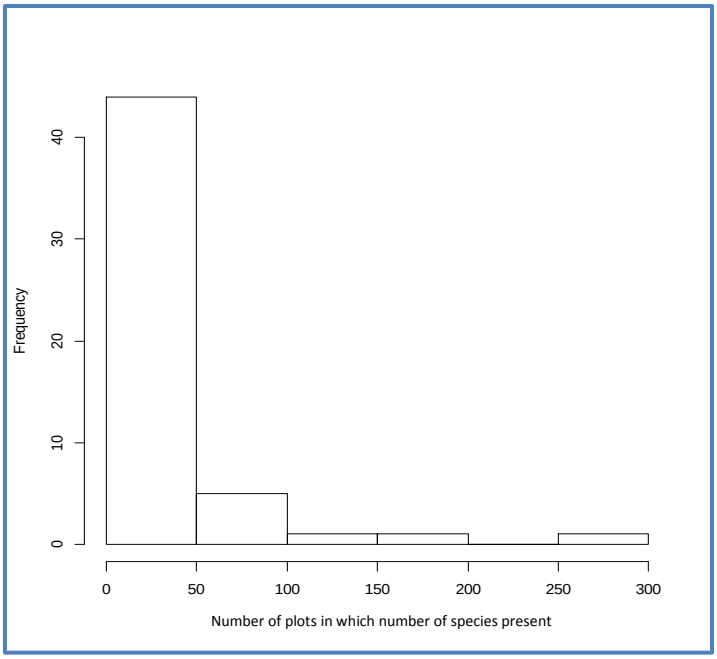


Figure 3.24: Combined sites – histogram of species presence by frequency.

The histogram demonstrates the species numbers per plot is heavily weighted to low numbers with one to ten species appearing in the greatest number of plots like that of the original result of Training sites.

Table 3.18: Individual species, occurrence in Combined sites by number and percent of plots (*n* = 407), and mean cover exhibited by each species – order is based on presence, followed by mean cover.

Species (presence order)	Number of plots in which species occurs	Percentage of plots in which species occurs	Mean cover (%) over plots in which species occurs
Sarcocornia quinqueflora	288	70.8	48.4
Juncus kraussii	180	44.2	44.6
Samolus repens	147	36.1	23.1
Selliera radicans	92	22.6	25.0
Distichlis distichophylla	73	17.9	16.8
Tecticornia arbuscula	62	15.2	44.7
Gahnia filum	56	13.8	35.4
Austrostipa stipoides	55	13.5	31.7
Isolepis cernua	45	11.1	13.9
Suaeda australis	43	10.6	17.8
Hemichroa pentandra	41	10.1	32.2
Disphyma crassifolium	39	9.6	25.4
Triglochin striata	39	9.6	4.7
Poa spp.	33	8.1	11.1
Apodasmia brownii	32	7.9	31.7
Sarcocornia blackiana	26	6.4	21.0
Leptinella longipes	26	6.4	19.1
Atriplex prostrata	21	5.2	7.1
Ficinia nodosa	17	4.2	25.8
Poa labillardierei	16	3.9	26.3
Atriplex paludosa	12	2.9	16.8
Schoenoplectus pungens	10	2.5	30.3
Lawrencia spicata	10	2.5	19.1
Apium prostratum	8	2.0	16.1
Plantago coronopus	8	2.0	11.5
Lilaeopsis polyantha	8	2.0	7.5
Puccinellia stricta	6	1.5	3.3
Wilsonia backhousei	5	1.2	38.0
Spergularia tasmanica	5	1.2	7.3
Lobelia anceps	5	1.2	7.3
Festuca arundinacea	4	1.0	17.6
Leptinella reptans	4	1.0	17.6
Schoenus nitens	4	1.0	12.0
Lachnagrostis billardierei	4	1.0	6.0
Zoysia macrantha	3	0.7	38.3
Brachyscome graminea	3	0.7	18.5
Phragmites australis	3	0.7	18.5
Atriplex cinerea	3	0.7	18.5

Species (presence order)	Number of plots in which species occurs	Percentage of plots in which species occurs	Mean cover (%) over plots in which species occurs
Mimulus repens	3	0.7	18.5
Baumea juncea	2	0.5	20.3
Wilsonia humilis	2	0.5	20.3
Lobelia irrigua	2	0.5	15.0
Carpobrotus rossii	2	0.5	9.0
Chenopodium glaucum	2	0.5	9.0
Leptocarpus tenax	2	0.5	9.0
Vellereophyton dealbatum	2	0.5	9.0
Eryngium vesiculosum	2	0.5	7.8
Angianthus preissianus	2	0.5	3.0
Limonium australe	1	0.2	15.0
Cotula coronopifolia	1	0.2	15.0
Lobelia alata	1	0.2	15.0
Tetragonia implexicoma	1	0.2	3.0

The most dominant species (Table 3.18) of the Combined sites was *S. quinqueflora* occurring in 71% (288) of plots, followed by *J. kraussii*, 44% (180) of plots, and *S. repens* 36% (147) of plots. These were the only species to occur in more than 30% of the plots state-wide, suggesting that they are the most dominant throughout. Three species, *Limonium australe, Cotula coronopifolia, L. alata,* and *Tetragonia implexicoma* were the least dominant species, occurring in just one plot each – 0.2% of all plots. Species being least dominant in Combined sites does not imply that they are rare, they just were not observed as often during all the vegetation surveys.

Kirkpatrick and Glasby (1981) found that species dominance in their study area of SE Tasmania, ranged from the most dominant being *S. quinqueflora*, followed by *S. repens, T. arbuscula, J. kraussii,* and *A. stipoides.* At the least dominant end were *L. brownii, Schoenus nitens, S. radicans* and *W. humilis.* They also found that only four native species are recorded solely in coastal saltmarshes, including *T. arbuscula, S. blackiana* and *W. humilis.* It is noted that *W. humilis* is now classified as rare in Tasmania (de Salas & Baker 2018), yet, not on the Australian mainland. Its cover here (in Table 3.18) appears high, this due to its very low structure and spreading form.

Species richness

Species richness ranges from one to 11 species per plot (per 4 square metres), with 63 (15.5%) plots housing a single species, 60 (14.7%) contain two, 99 (24.3%) contain 3 species, 67 (16.5%) contain 4 species, 51 (12.5%) contain 5 species, 36 (8.9%) contain 6 species, 18 (4.4%) contain 7 species, seven (1.7%) plots have 8 species, while nine, 10 and 11 species are found in two plots each (0.5%). Total plant cover per plot ranges from just 37.5% to over 200%, which appears extraordinarily high. The low plant cover indicates plots with high bare ground cover (excluded from the data matrix). The high plant cover indicates two plots – ABNP3 (198% cover) and ELPS5 (207%) – have a high species richness and number of vegetation layers thereby increasing total cover. Both plots have no bare ground; ABNP3 has four graminoid species and extensive ground cover of seven herb species, while ELPS5 has two graminoid species – their structural form covering 100% and four herb species covering a similar amount (or perhaps the high cover value is the over-exuberance of the assessor!). It is noted that plant cover exceeding 100% is a common occurrence in Tasmanian saltmarshes.

Species average and mean cover

The average number of species per plot was 3.59 (a slight decrease from the Training sites of 3.94). Mean species cover as a function of species presence is shown in Figure 3.25 (following page).

The most widespread species – *S. quinqueflora* (Sar_qui) – had very wide occupancy and the greatest cover (this species is a spreading ground cover plant often displaying "sweeping lawns", hence high cover). This was followed by *J. kraussii* (Jun_kra), a species with a more medium spread, but still very high in cover (its structural tussocky, spreading form leads to high cover). Displaying medium occupancy and medium cover are *S. repens* (Sam_rep) and *S. radicans* (Sel_rad). Those species with low range, but with high cover include *T. arbuscula* (Tec_arb) and *G. filum* (Gah_fil) with *A. stipoides* (Aus_sti), *H. pentandra* (Hem_pen) and *A. brownii* (Apo_bro) closely behind. Species with a low range and a medium cover include *S. blackiana* (Sar_bla). *D. crassifolium* (Dis_cra) and *S. australis* (Sua_aus), and those with low range and low cover include *S. tasmanica* (Spe_tas), *T. striata* (Tri_str) and *P. stricta* (Puc_str).

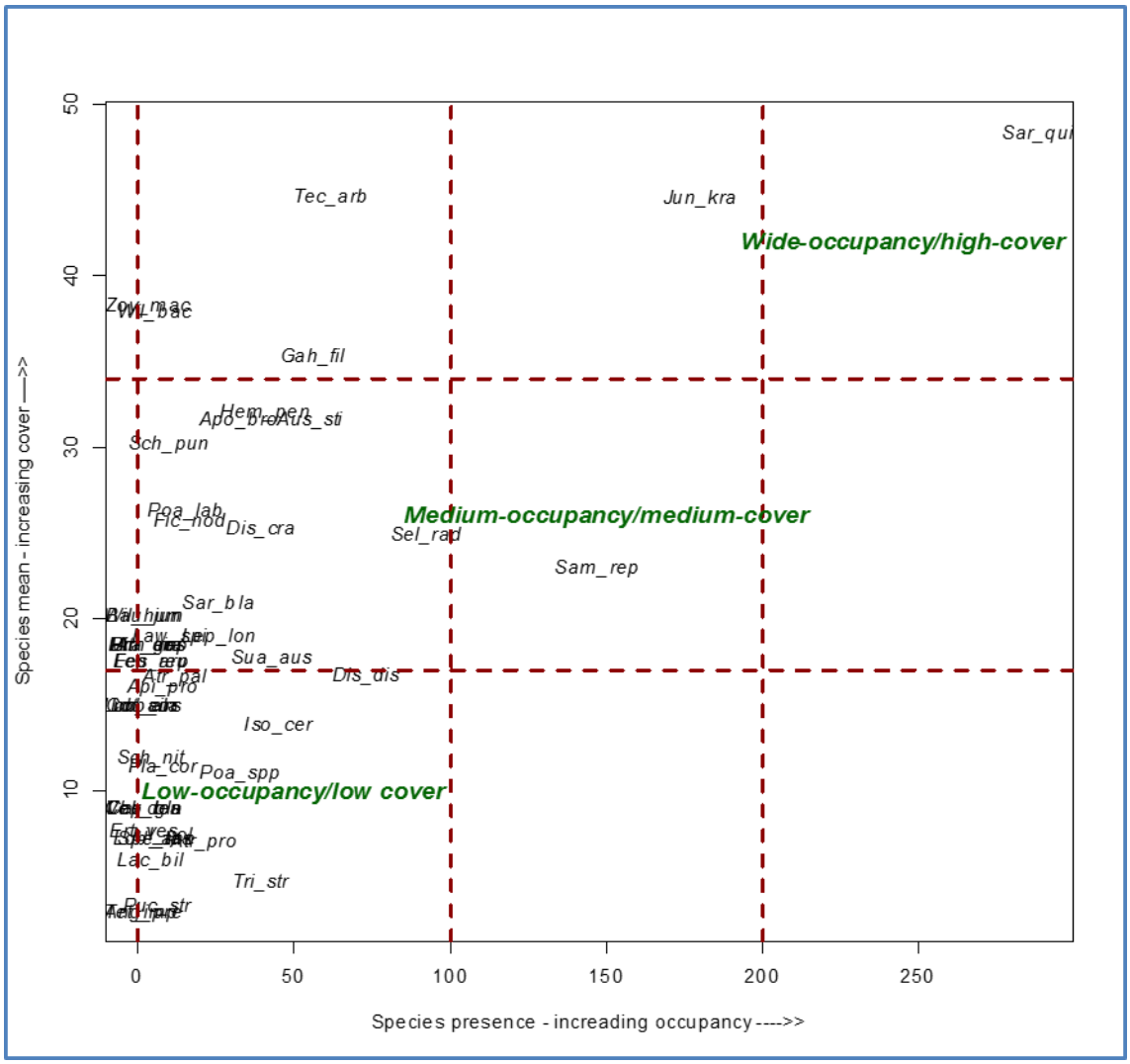


Figure 3.25: Species (by name) presence as a function of species mean cover based on Combined sites data.

3.4.6 Ordination

Two types of ordination were analysed – PCA and an nMDS.

PCA

Introduced species were removed from the dataset; and rare species were omitted by replacing cover values of 1 and 2 with zero.

A scree chart (with a "broken stick" line) displaying each of the first 10 coordinates along with eigenvalues is shown in Figure 3.26. The scree plot shows the first five principle components (PCs) are above the broken stick, indicating they explain most of the variation in the PCA. Eigenvalues and percent of variance for unconstrained axes (first 10 of 50 principal coordinates) are presented in Table 3.19.

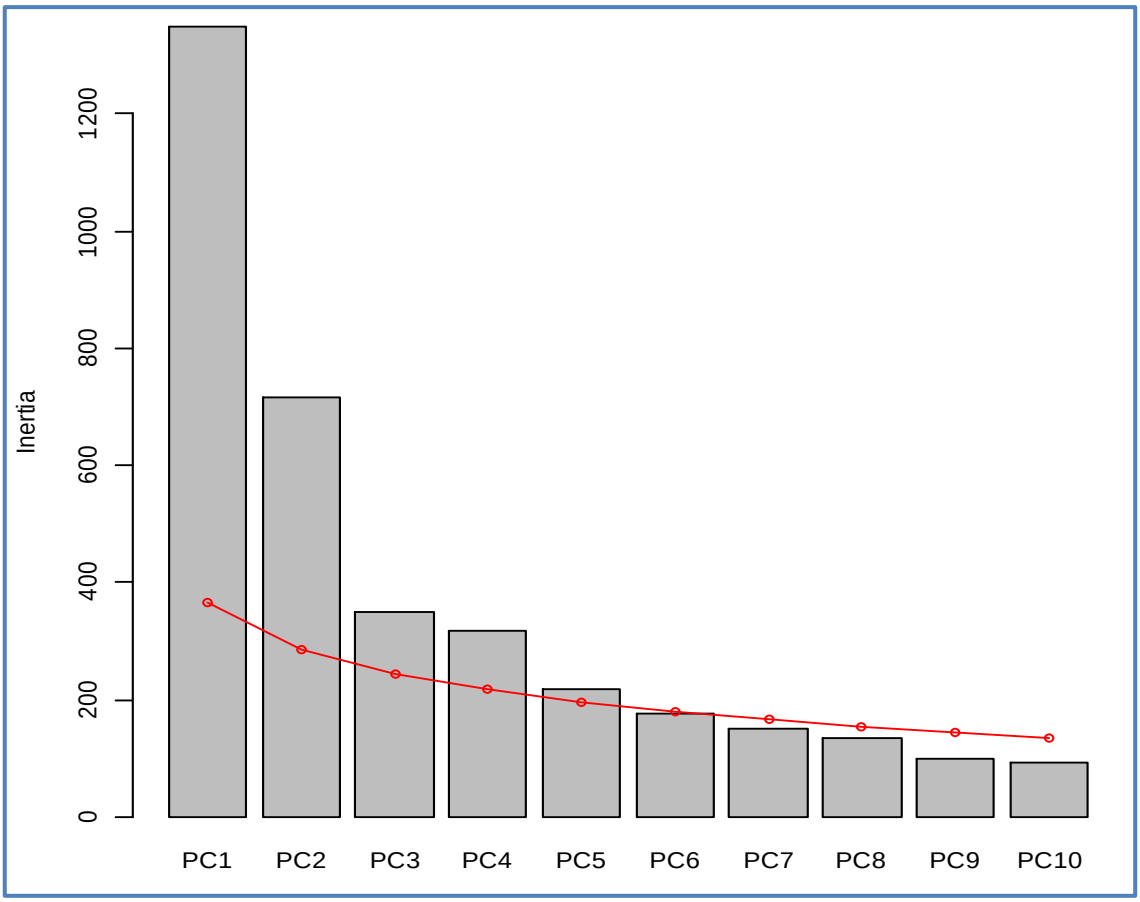


Figure 3.26: Scree chart of 10 coordinates overlain by a "broken stick" line (in **red**). The first five PCs are above the broken stick indicating statistical importance within the PCA.

Table 3.19: Eigenvalues of first 10 principal components (PC) of ordination.

PCA	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigen value	1350.0	717.6	351.1	318.6	219.0	177.9	151.3	136.6	97.2	85.7
% of variance	33.08	17.58	8.60	7.81	5.37	4.36	3.71	3.35	2.38	2.10

The total inertia (the sum of all 50 eigenvalues – there are 50 principal components) is 4081. Each eigenvalue explains a portion of the total variance denoting which PCs are important. The first axis (1 of 50) explains 1350/4081 = 33.08% of total variance, the second axis explains 717.6/4081 = 17.58%, therefore the first two axes explain 50.66% of the total variance in the analysis.

The PCA ordination showing the relationship between plots and plant species, is presented in Figure 3.27.

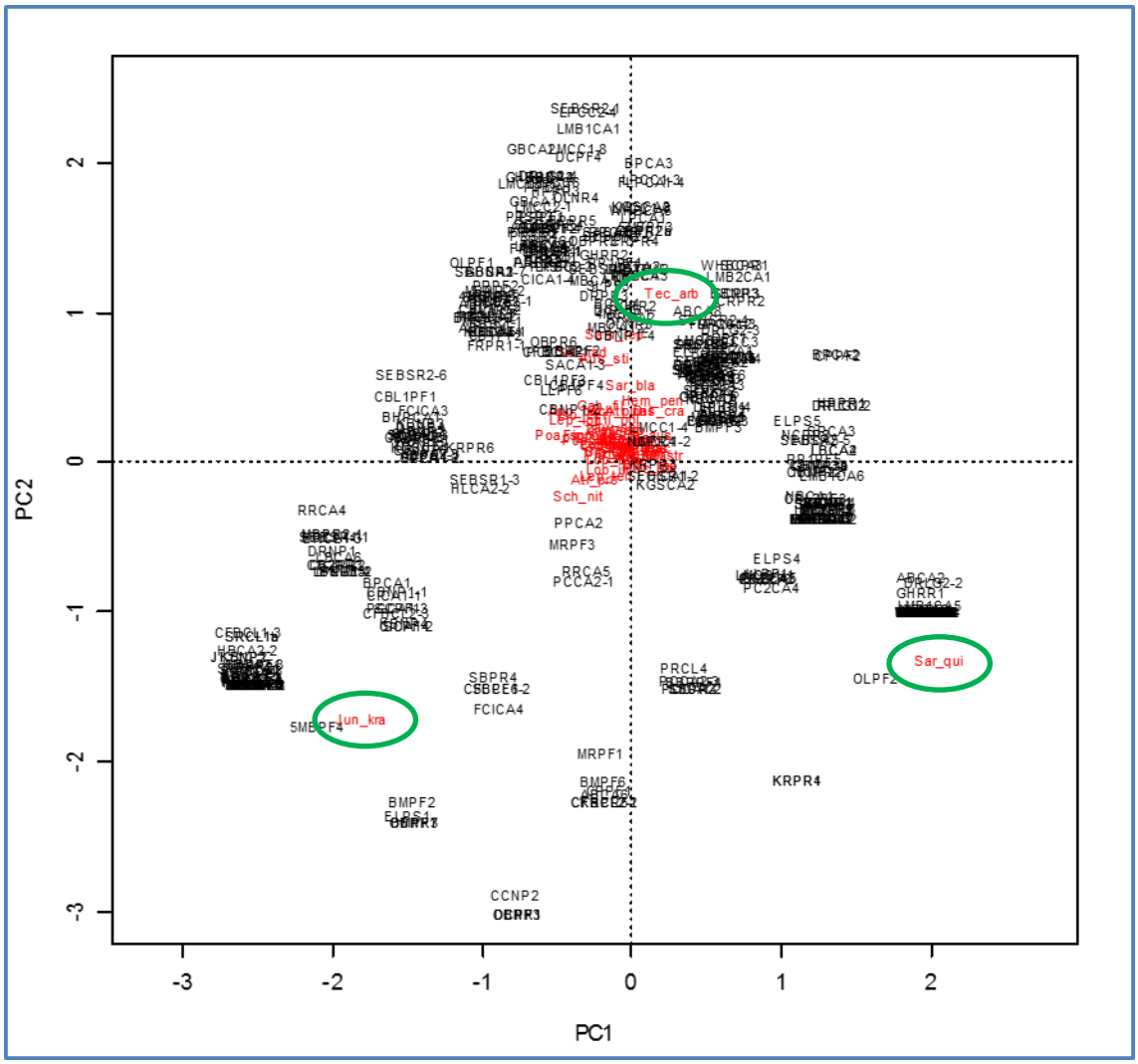


Figure 3.27: A PCA ordination (coordinates PC1 and PC2) demonstrating relationships between individual plots and plant species. The diagram highlights similarities between many plots (as seen in a 2D image) and three distinctive species (circled in green) – *J. kraussii, S. quinqueflora* and *T. arbuscula* – which shows high dissimilarities between each of the three species.

Most plants cluster near the centre of the ordination, as do the plots. However, two species, *J. kraussii* (Jun_kra) and *T. arbuscula* (Tec_arb) are positioned in opposite sectors of the ordination, indicating little if any relationship with *S. quinqueflora* (Sar_qui) positioned away from the main group of plant species in its own quadrant (thus demonstrating the importance of PC1 and PC2). The positioning of these three species indicates that they are important saltmarsh plants and key indicators within saltmarshes.

Again, by means of a PCA, the relationship between plots and vegetation groups are presented in Figure 3.28.

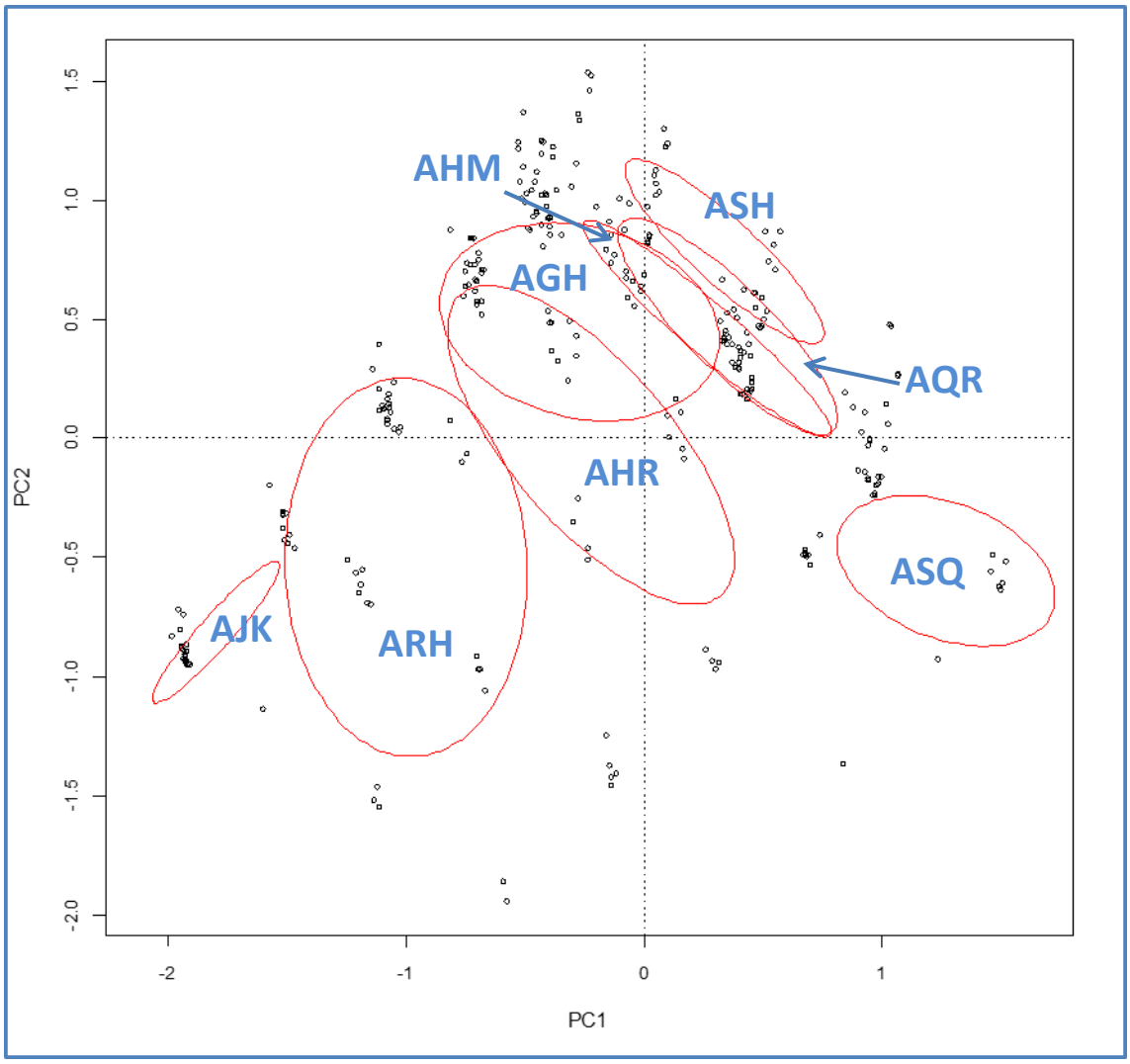


Figure 3.28: PCA ordination (coordinates PC1 and PC2) indicating relationships between individual plots (presented as points to minimise clutter) and vegetation groups. The diagram highlights similarities between some groups – AHM, ASH and AQR – these three groups share several plant species at differing levels/concentrations. Strong dissimilarities are drawn between AJK, ARH, AHR and ASQ.

The PCA ordination summarises the relationship between vegetation communities and plots. Many plots appear clustered in the top half of the ordination, as do four vegetation communities – AGH, AHM, ASH and AQR – this demonstrating that there is an inter-relationship between the four groups as they share many individual plant species, principally herbs, within each respective community. Three groups are distinctive in being entirely separate to other groups – AJK, ASQ and ARH. Two, AJK and ASQ, have no relationship; each group is a mono species community. Vegetation community ARH is somewhat aligned to AJK, *J. kraussii* being the primary species in both groups, with community AHR being separated further from AJK, yet close to ARH. Both ARH and AHR share similar plant species, however in differing concentrations, the key species being *J. kraussii*. This species is totally dominant in AJK

(as a single species), greater that 50% dominant in ARH with understorey/ground cover herbs at a lower (<50%) cover level, but reversed in AHR, where herbs exhibit greater than 50% cover (thus drawn closer to the herb communities, e.g. AHM), while *J. kraussii* being somewhat less (<50%). This ordination clearly demonstrates the "positioning" of the three groups and their individual close relationships to each other (AJK, AHR and ARH) and the increasing distant relationships to the remaining communities (AHM, ASH and AQR). Another notable aspect in the ordination is the positioning of community AGH (graminoids and herbs). This vegetation community principally contains *A. stipoides, G. filum,* some *J. kraussii,* and has herbs (e.g. *S. quinqueflora, S. blackiana, D. crassifolium*) as groundcover. The AGH community is placed between AHR and AHM, demonstrating a closer association to the two communities; its relationship to AHR is defined by the presence of *J. kraussii*, and its relationship to AHM is defined by the presence of ground cover herbs. This observation is well evidenced in the field, thus instilling confidence in this analysis.

nMDS

Introduced species were removed from the dataset; however, dissimilar to PCA ordination, rare species were retained – all cover values were utilised.

Contrary to PCA ordination, an nMDS ordination is based on stress, the lower the value the better. The nMDS ordination is generally arranged on two dimensions (k=2). To reduce stress, ordination can be arranged at k=3 (three dimensions). A two-dimension ordination can only result in one two-dimensional plot with nMDS1 and nMDS2 as axes. However, a three-dimension plot will have nMDS1, nMDS2 and nMDS3 (axes) viewed in three plots using combinations of these axes – nMDS1 and nMDS2, nMDS1 and nMDS3, followed by nMDS2 and nMDS3.

The nMDS dimensions and stress results are tabled (Table 3.20).

Table 3.20: Dimensions attempted, stress and tries results.

Dimensions (k =)	Stress	Tries	Dimensions (k =)	Stress	Tries
2	0.1853335	20	3	0.1277787	20
2	0.1853335	20	3	0.1277746	20
2	0.1851641	20	3	0.1277568	20
2	0.1853350	20	3	0.1225190	20

By conducting an nMDS at k=3 (Figure 3.30), the stress is reduced by over 35% from an nMDS at k=2 (Figure 3.29).

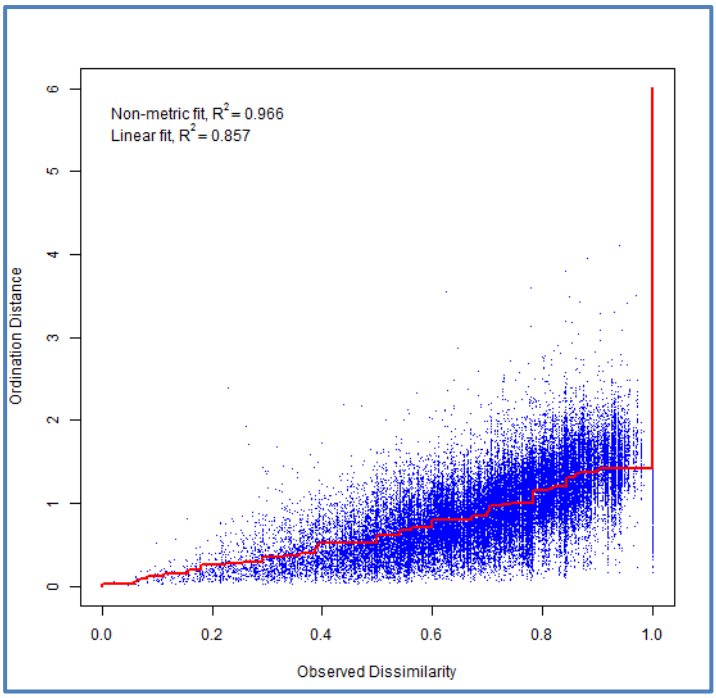


Figure 3.29: An nMDS stress chart based on k=2.
Stress = 0.1851641
Best solution in 20 tries.

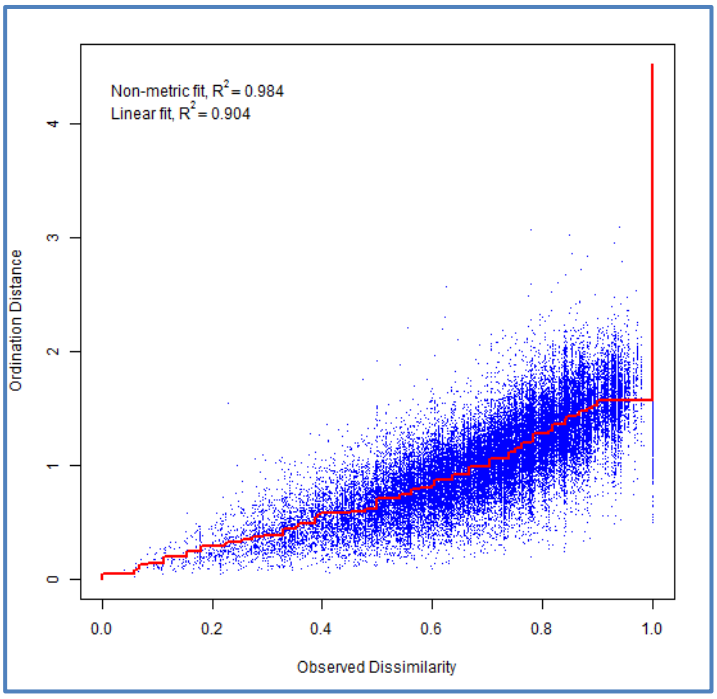


Figure 3.30: An nMDS stress chart based on k=3.
Stress = 0.1277519
Best solution after 20 tries.

As the nMDS k=2 stress value was less than 0.2 (an acceptable level), the 2-dimensioal nMDS ordination was retained – and was used in the following sections.

Plant species-based nMDS ordination

Significant ($p<0.001$) plant species are tabled in Table 3.21.

Table 3.21: Significant plant species at p<0.001 with nMDS1 and nMDS2 vectors (ordered to r^2 values). Species names provided in full.

Species	nMDS1	nMDS2	r^2	p-value
Sarcocornia quinqueflora	0.89548	-0.44510	0.6175	0.001
Juncus kraussii	-0.71850	-0.69553	0.6011	0.001
Tecticornia arbuscula	0.68862	0.72512	0.2709	0.001
Apodasmia brownii	-0.99146	0.13040	0.1573	0.001
Selliera radicans	-0.56873	0.82252	0.1535	0.001
Leptinella longipes	-0.80987	0.58661	0.1457	0.001
Sarcocornia blackiana	0.44413	0.89596	0.1347	0.001
Disphyma crassifolium	0.63085	0.77591	0.1337	0.001
Schoenoplectus pungens	-0.58140	0.81362	0.1144	0.001
Poa spp.	-0.86295	0.50530	0.0984	0.001
Gahnia filum	-0.56329	0.82626	0.0863	0.001
Samolus repens	-0.12718	0.99188	0.0838	0.001
Austrostipa stipoides	-0.26789	0.96345	0.0807	0.001
Liliaeopsis polyantha	-0.63491	0.77259	0.0797	0.001
Poa lab	-0.99901	-0.04443	0.0729	0.001
Ficinia nodosa	-0.83545	0.54957	0.0707	0.001
Isolepis cernua	-0.72966	0.68382	0.0505	0.001
Distichlis distichophylla	-0.60381	0.79713	0.0495	0.001
Hemichroa pentandra	0.37796	0.92582	0.0450	0.001
Atriplex paludosa	0.08583	0.99631	0.0417	0.001
Lawrencia spicata	-0.20908	0.97790	0.0409	0.001

Permutation: free. Number of permutations: 999

An nMDS ordination of plots fitted with plant species to p<0.001 is presented in Figure 3.31.

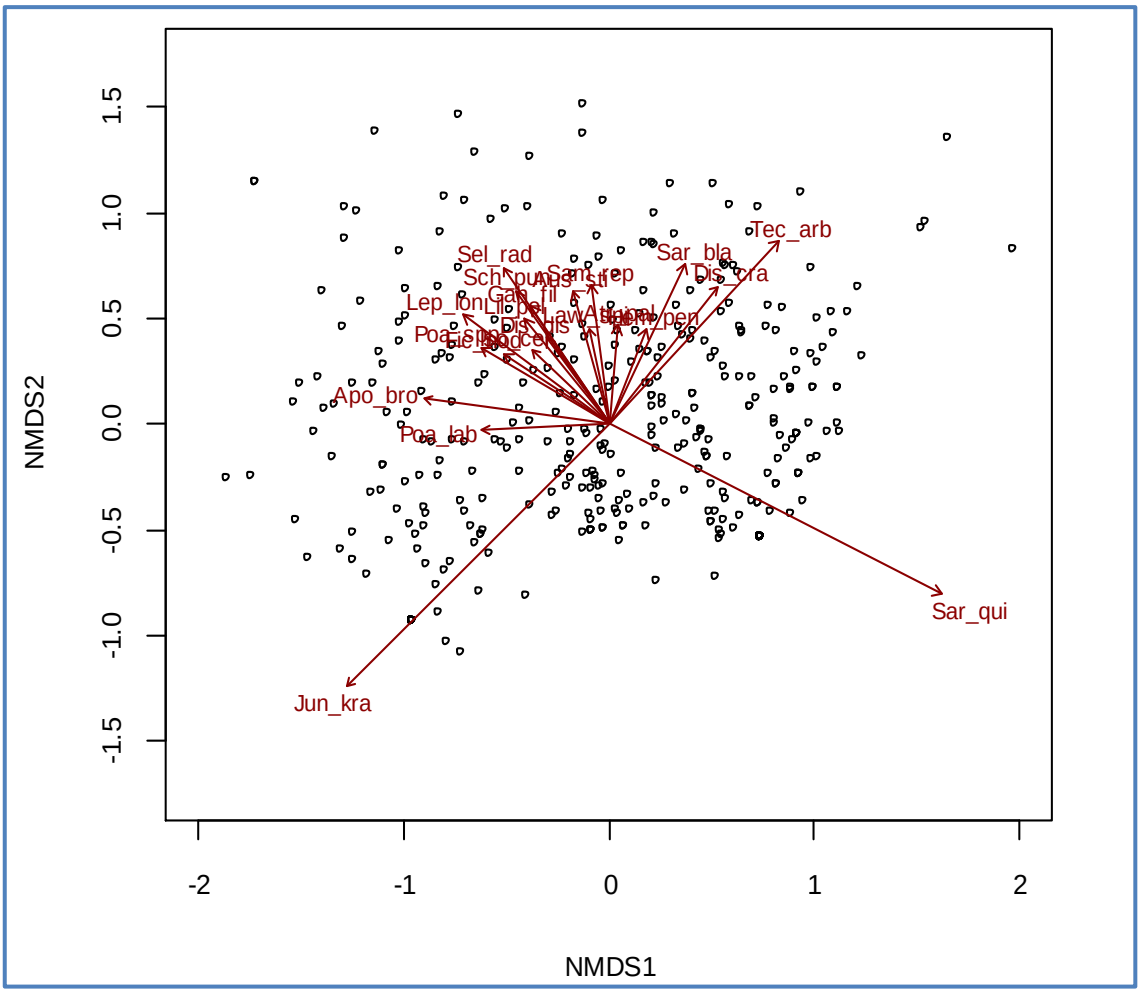


Figure 3.31: An nMDS (at k=2) of plots (individual points) fitted with plant species at p<0.001. Like the PCA ordination, the diagram highlights similarities between many plots (as seen in a 2D image) and three distinctive species – *J. kraussii, S. quinqueflora* and *T. arbuscula* – all of which shows high dissimilarities between each other.

Focusing on the key species – *J. kraussii* (Jun_kra) is negatively orientated to both nMDS1 and nMDS2, while *T. arbuscula* (Tec_arb), inverse to *J. kraussii*, is positively orientated to both nMDS1 and nMDS2 axes, thus demonstrating little, if no relationship between the two species – this is evident in the field. In the case of *S. quinqueflora* (Sar_qui), this species is positively orientated to nMDS1, and negatively orientated to nMDS2. This signifies that there is an association between *J. kraussii* and *T. arbuscula,* where *S. quinqueflora* appears to "have a foot in each camp", again, this relationship is evident in the field. The nMDS also portrays the strong association between *T. arbuscula* and two ground cover herbs, *S. blackiana* (Sar_bla) and *D. crassifolium* (Dis_cra), which is strongly displayed in the field.

Vegetation communities based on nMDS

Vegetation communities charted on an nMDS are displayed in Figure 3.32.

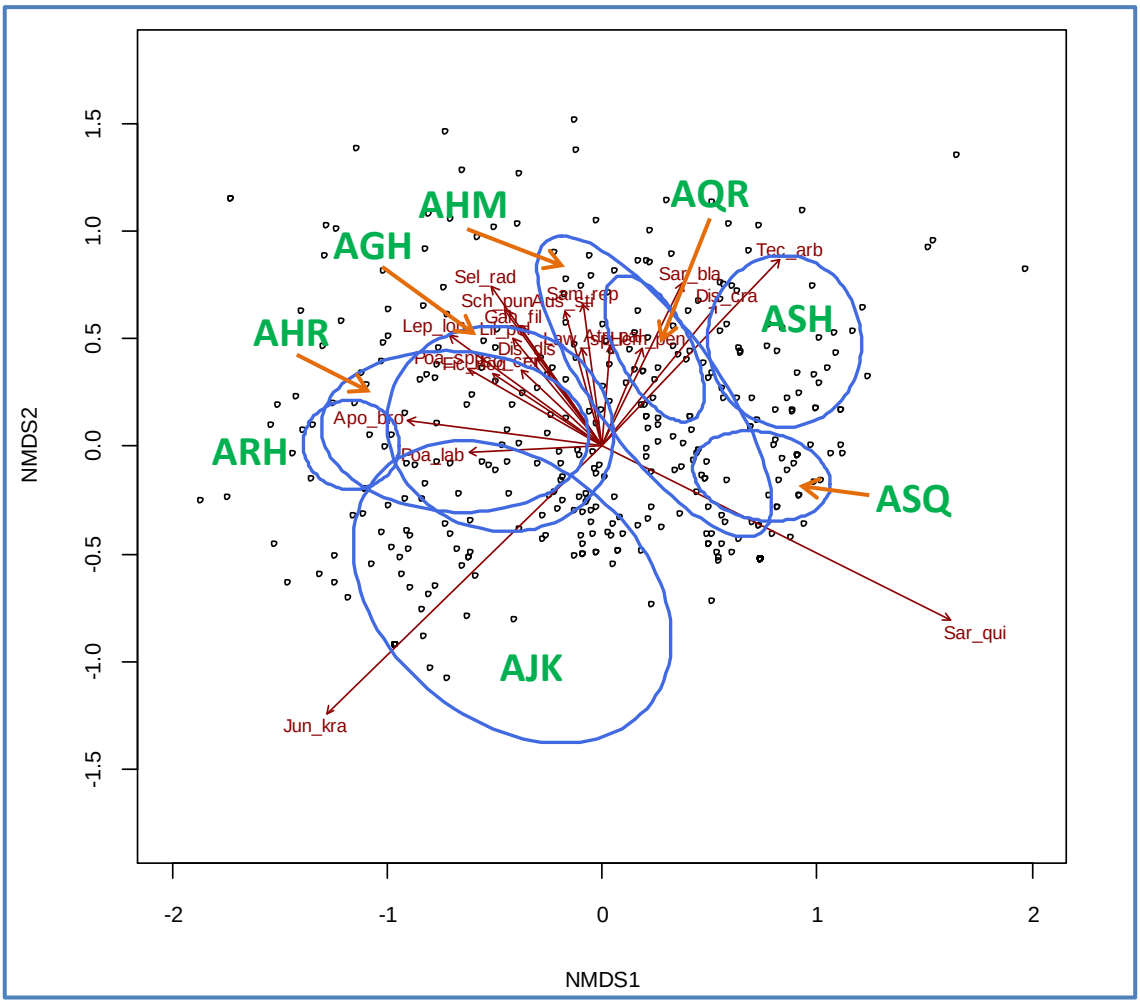


Figure 3.32: an nMDS ordination (coordinates nMDS1 and nMDS2) indicating relationships between individual plots (presented as points to minimise clutter) and vegetation groups. The diagram highlights close associations between some groups – AHM, AGH and AQR – these three groups share several plant species at differing levels/concentrations. Strong dissimilarities are drawn between AJK, ASH and ASQ.

This nMDS summarises the relationship between vegetation communities. Most communities appear clustered in the centre of the ordination, with three communities exhibiting little if any association to each other. In many aspects this ordination is similar to the PCA ordination (Figure 3.28 page 3.71), where strong associations are displayed between herb communities. Again, of note is the marked distinction between AJK, ASQ and ASH, reinforced by field observations. This also highlights the ease in determining these three communities in the field, and the closeness of the remaining communities (particularly AHM, AHR and ARH), demonstrating the difficulty at times in defining them during field assessments.

3.4.7 Response to climate variables

Significant ($p<0.001$) climate vectors are tabled in Table 3.22.

Table 3.22: Significant climate variable vectors at p<0.001 with nMDS1 and nMDS2 vectors (ordered to r^2 decreasing values).

Variable	Code	nMDS1	nMDS2	r^2	p-value
Mean annual maximum temperature	T_Max_Mean	0.99806	0.06223	0.2488	0.001
Lowest annual rainfall recording	Rain_Low	-0.96750	-0.25286	0.2284	0.001
Mean annual rainfall	Rain_Mean	-0.97445	0.22462	0.2278	0.001
Highest maximum annual temperature	T_Max_High	0.96157	0.27455	0.2018	0.001
Mean lowest daily solar exposure	SR_Low	0.96266	0.27070	0.1343	0.001
Mean highest daily solar exposure	SR_High	0.97719	0.21235	0.1089	0.001
Mean annual minimum temperature	T_Min_Mean	0.61676	0.78715	0.0431	0.001
Lowest minimum annual temperature	T_Min_Low	0.61721	0.78680	0.0329	0.001

Permutation: free. Number of permutations: 999

Plant species nMDS ordination and climate vectors

A plant species nMDS ordination fitted with climate vectors is displayed in Figure 3.33, and, an nMDS ordination fitted with significant plant species (p<0.001), climate variables – rainfall, temperature and solar exposure – is displayed in Figure 3.34 (following page).

Specific plant species appear to dominate key climatic zones. *J. kraussii* is an indicator of a wet, cooler climate, while *T. arbuscula* designates a dry, warmer climate and *S. quinqueflora* is found in drier and cooler areas. Of the 52 species identified during field assessments, eight (15%) occupy a wet, cool environment, four (8%) are found in dry, cool areas, 13 (25%) prefer a dry warm environment, and the remainder, 27 species (52%), are located in wet, warm areas. This is significant, as Tasmania moves to a wetter, warmer climate driven by climate change (Grose *et al.* 2012), the survival of many of Tasmania's coastal saltmarsh plant species, for example, succulent herbs *D. crassifolium, S. radicans,* and saline grasses, *A. stipoides, G. filum*, can be assured (Prahalad & Kirkpatrick in press). This may appear not to bode well for those species preferring dry cool environments, however, some species, such as *S. quinqueflora*, are very adaptable and found in six (AQR, AHM, ASH, AHR, ARH, AGH) of the eight vegetation communities ensuring long-term survival. What may be lost is community ASQ, where *S. quinqueflora* is found as a mono species, and that community mostly found in the dryer cool zone.

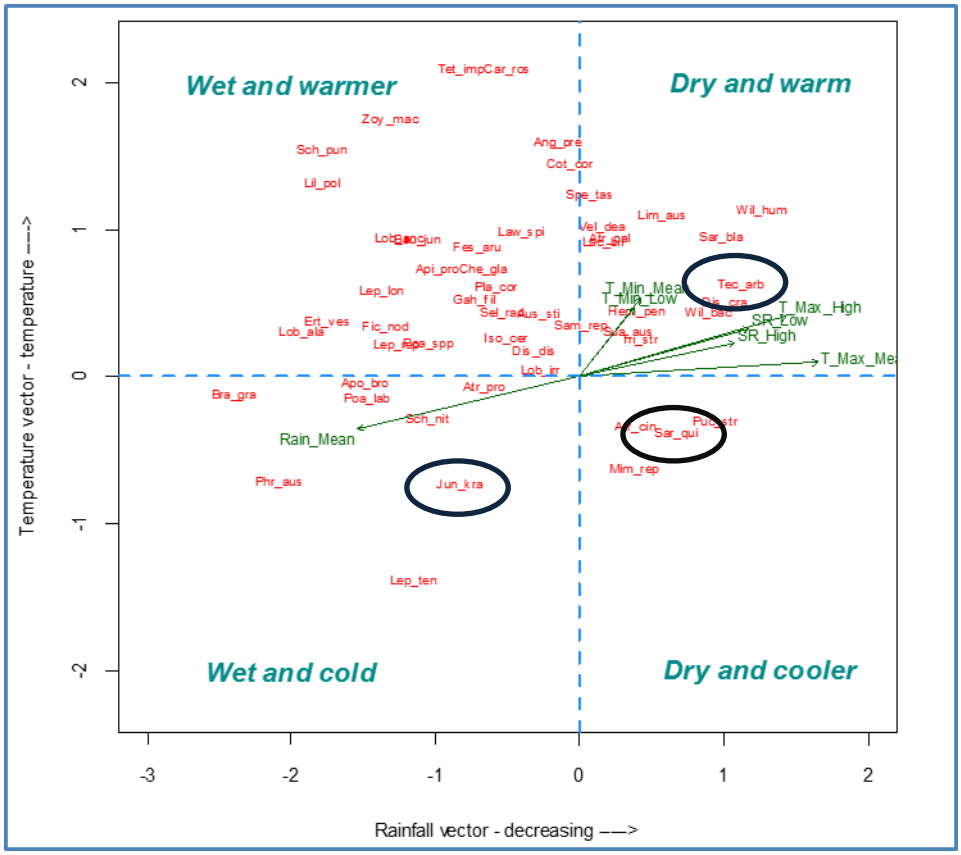


Figure 3.33: nMDS of plant species fitted with climate variables and partitioned to climatic zones. Key plant species are identified by dark blue ovals.

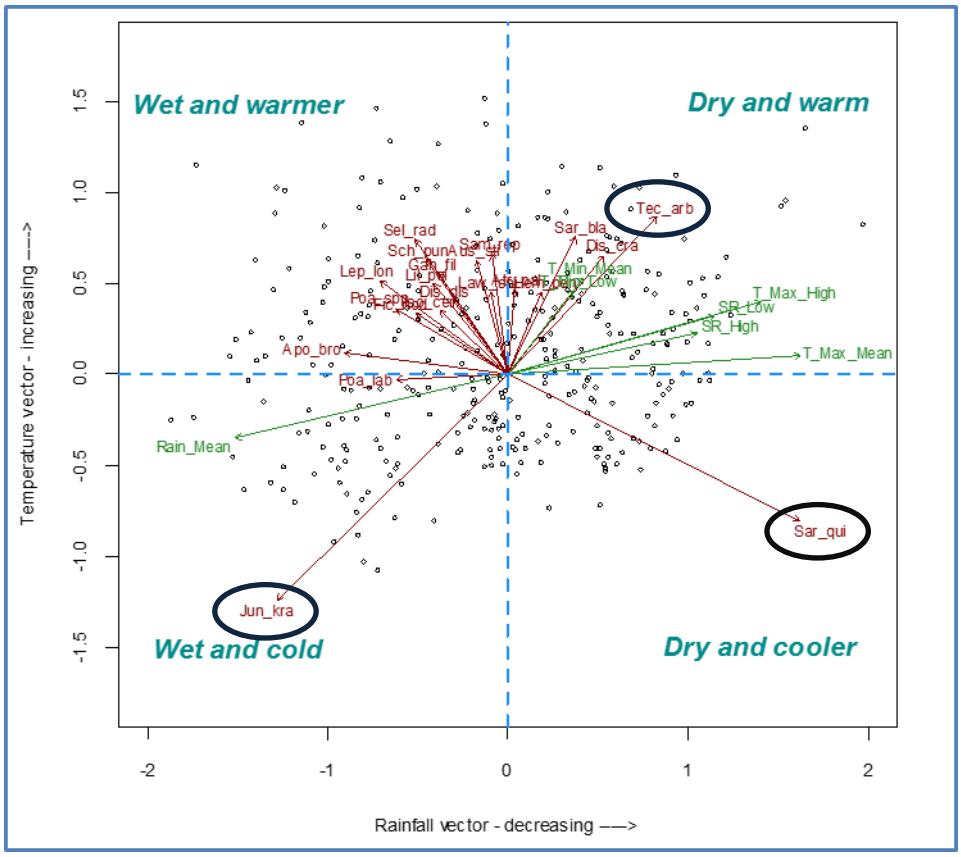


Figure 3.34: A field plot nMDS (plots marked as points to reduce clutter) fitted with plant species (at $p<0.001$) and long-term climate variables (at $p<0.001$) sectioned to climatic zones. Key plant species are identified by dark blue ovals.

Note: The nMDS (Figure 3.34) is slightly different to the one above (Figure 3.33) as horizontal and vertical scales have different ranges.

Vegetation communities and climate variables

Individual vegetation communities were aligned to climatic variables of mean and minimum annual rainfall, mean maximum and minimum annual temperatures, maximum highest temperature and minimum lowest temperature, and mean highest and lowest daily solar exposure, and tested using boxplots (Figures 3.35 to 3.42) and ANOVA.

Note: similar figure pairs, such as, rainfall, temperature, display the same data range to aid better visualisation of results. Observations on Figure 3.35 to 3.42 are provided with Table 3.24 – Tukey groups.

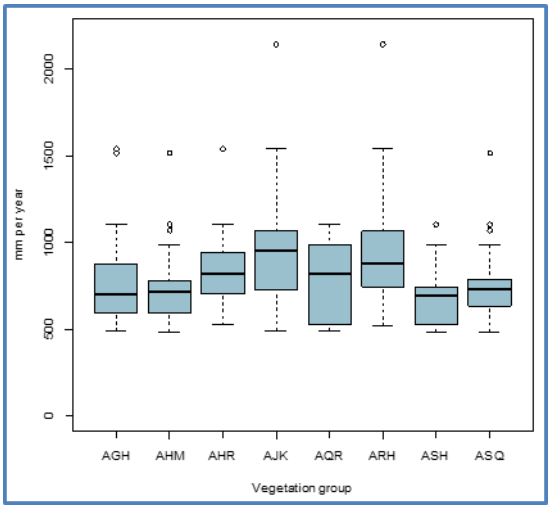


Figure 3.35: Vegetation communities and mean annual rainfall.

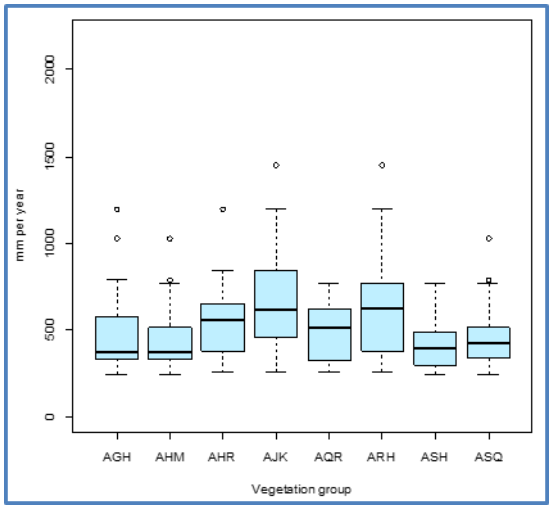


Figure 3.36: Vegetation communities and lowest annual rainfall recorded.

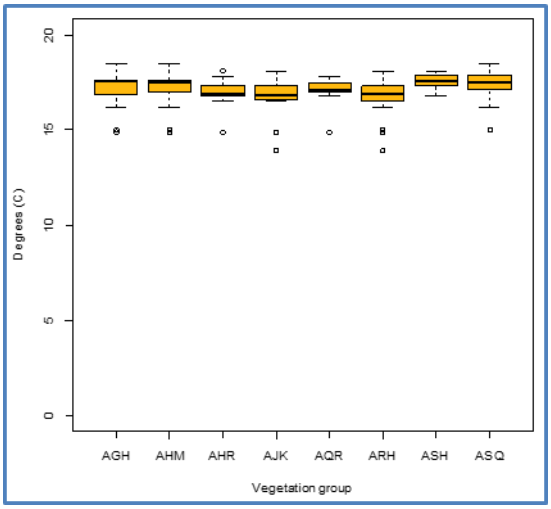


Figure 3.37: Vegetation communities and mean annual maximum temperature.

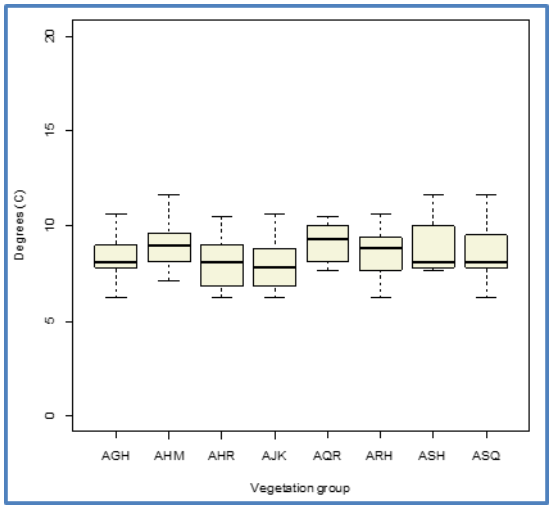


Figure 3.38: Vegetation communities and mean annual minimum temperature.

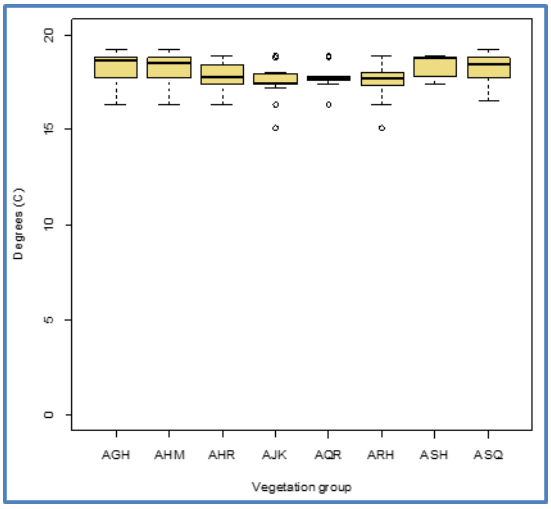


Figure 3.39: Vegetation communities and highest annual maximum temperature.

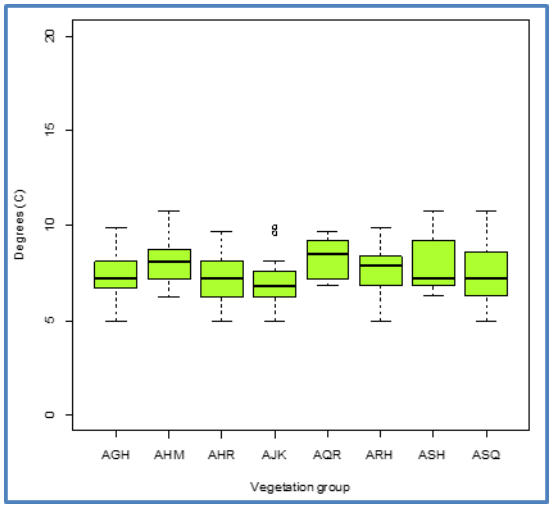


Figure 3.40: Vegetation communities and lowest annual minimum temperature.

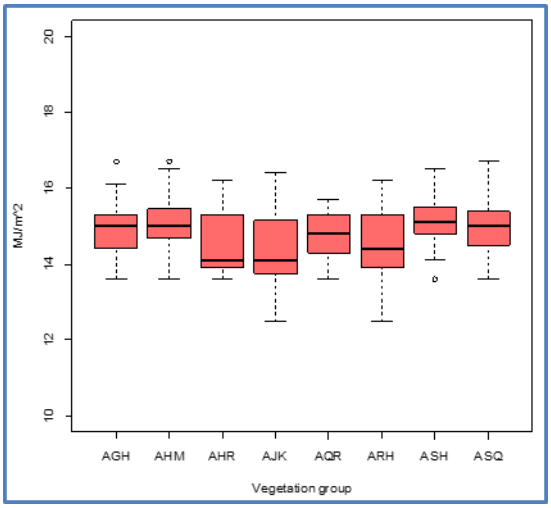


Figure 3.41: Vegetation communities and mean highest daily solar exposure.

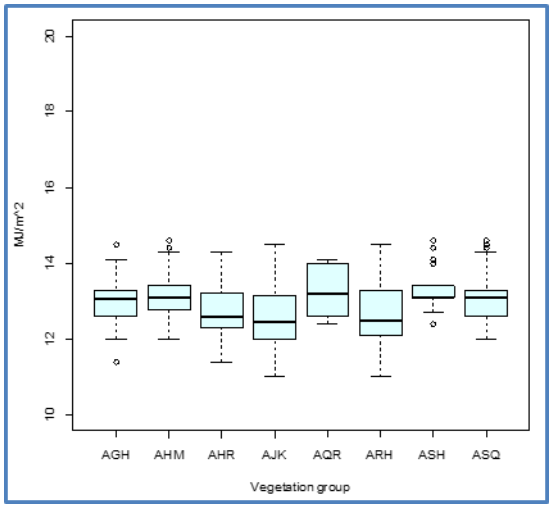


Figure 3.42: Vegetation communities and mean lowest daily solar exposure.

ANOVA outputs of climate factors are presented in Table 3.23.

Table 3.23: ANOVA results for climate variables – sorted by order of boxplots (see Figures 3.35 to 3.42).

Variable	Code	Df	F value	p-value	
Mean annual rainfall	Rain_Mean	7	8.339	1.62e-09	***
Lowest annual rainfall recording	Rain_Low	7	9.522	5.96e-11	***
Mean annual maximum temperature	T_Max_Mean	7	9.907	2.04e-11	***
Mean annual minimum temperature	T_Min_Mean	7	5.596	3.61e-06	***
Highest maximum annual temperature	T_Max_High	7	9.408	8.19e-11	***
Lowest minimum annual temperature	T_Min_Low	7	4.951	2.19e-05	***
Mean highest daily solar exposure	SR_High	7	7.031	6.40e-08	***
Mean lowest daily solar exposure	SR_Low	7	7.206	3.91e-08	***

All climate variables display significant differences between vegetation communities. The very low p-value for each indicates that there is at least one vegetation group within each variable that is significantly different to all other communities.

Tukey's HSD test results are presented in Table 3.24.

Table 3.24: Group means, standard error, range (minimum to maximum) and Tukey groups for each climate variable. Within each climate variable, the values followed by the same letter (Tukey Groups) are not different at p<0.05.

Climate Variable	Veg group	*n*	Mean ± Std Error	Min	Max	Tukey groups
Mean annual rainfall	AGH	66	770.6 ± 29.52	492	1543	bc
	AHM	63	759.3 ± 32.11	485	1518	bc
	AHR	33	882.4 ± 50.19	526	1543	ab
	AJK	36	966.4 ± 54.24	492	2143	a
	AQR	18	806.3 ± 50.25	492	1104	abc
	ARH	57	965.9 ± 50.23	521	2143	a
	ASH	49	672.7 ± 21.94	485	1104	c
	ASQ	85	743.6 ± 21.27	485	1518	bc
Lowest annual rainfall recorded	AGH	66	467.0 ± 25.34	247	1196	bc
	AHM	63	459.2 ± 25.43	247	1026	bc
	AHR	33	597.5 ± 46.58	256	1196	ab
	AJK	36	662.7 ± 47.23	256	1449	a
	AQR	18	502.5 ± 39.58	256	768	abc
	ARH	57	647.5 ± 39.72	260	1449	a
	ASH	49	411.0 ± 17.67	247	768	c
	ASQ	85	457.0 ± 18.21	247	1026	c
Mean annual maximum temperature	AGH	66	17.2 ± 0.10	14.9	18.5	abc
	AHM	63	17.3 ± 0.11	14.9	18.5	ab
	AHR	33	17.0 ± 0.12	14.9	18.1	bcd
	AJK	36	16.7 ± 0.15	13.9	18.1	cd
	AQR	18	17.1 ± 0.15	14.9	17.8	abcd
	ARH	57	16.6 ± 0.14	13.9	18.1	d
	ASH	49	17.6 ± 0.05	16.8	18.1	a
	ASQ	85	17.4 ± 0.06	15.0	18.5	ab
Mean annual minimum temperature	AGH	66	8.3 ± 0.13	6.2	10.6	abc
	AHM	63	9.0 ± 0.13	7.1	11.6	a
	AHR	33	8.1 ± 0.23	6.2	10.5	bc
	AJK	36	7.9 ± 0.18	6.2	10.6	c
	AQR	18	9.2 ± 0.24	7.7	10.5	a
	ARH	57	8.5 ± 0.17	6.2	10.6	abc
	ASH	49	8.9 ± 0.18	7.7	11.6	ab
	ASQ	85	8.6 ± 0.14	6.2	11.6	ab

Climate Variable	Veg group	*n*	Mean ± Std Error	Min	Max	Tukey groups
Highest maximum annual temperature	AGH	66	18.2 ± 0.10	16.3	19.2	ab
	AHM	63	18.2 ± 0.10	16.3	19.2	ab
	AHR	33	17.9 ± 0.12	16.3	18.9	bc
	AJK	36	17.6 ± 0.13	15.1	18.9	c
	AQR	18	17.8 ± 0.14	16.3	18.9	bc
	ARH	57	17.5 ± 0.13	15.1	18.9	c
	ASH	49	18.4 ± 0.08	17.4	18.9	a
	ASQ	85	18.2 ± 0.07	16.5	19.2	ab
Lowest minimum annual temperature	AGH	66	7.3 ± 0.14	5.0	9.9	bc
	AHM	63	8.1 ± 0.14	6.2	10.8	a
	AHR	33	7.2 ± 0.25	5.0	9.7	bc
	AJK	36	6.9 ± 0.18	5.0	9.9	c
	AQR	18	8.4 ± 0.26	6.8	9.7	a
	ARH	57	7.6 ± 0.18	5.0	9.9	abc
	ASH	49	7.9 ± 0.20	6.3	10.8	ab
	ASQ	85	7.6 ± 0.16	5.0	10.8	abc
Mean highest daily solar exposure	AGH	66	14.9 ± 0.08	13.6	16.7	ab
	AHM	63	15.1 ± 0.09	13.6	16.7	a
	AHR	33	14.5 ± 0.13	13.6	16.2	bc
	AJK	36	14.5 ± 0.15	12.5	16.4	c
	AQR	18	14.7 ± 0.16	13.6	15.7	abc
	ARH	57	14.5 ± 0.11	12.5	16.2	c
	ASH	49	15.1 ± 0.09	13.6	16.5	a
	ASQ	85	15.0 ± 0.08	13.6	16.7	a
Mean lowest daily solar exposure	AGH	66	13.0 ± 0.07	11.4	14.5	abc
	AHM	63	13.2 ± 0.08	12.0	14.6	ab
	AHR	33	12.7 ± 0.14	11.4	14.3	bc
	AJK	36	12.6 ± 0.14	11.0	14.5	c
	AQR	18	13.2 ± 0.15	12.4	14.1	ab
	ARH	57	12.7 ± 0.11	11.0	14.5	bc
	ASH	49	13.3 ± 0.09	12.4	14.6	a
	ASQ	85	13.1 ± 0.07	12.0	14.6	ab

Mean annual rainfall – 3 levels of difference: vegetation communities AHR, AJK, AQR and ARH are similar in terms of means (Tukey group **a**), communities AGH, AHM, AHR, AQR and ASQ display commonality (group **b**), while AGH, AHM, AQR ASH and ASQ display similarity (**c**).

Although means of annual rainfall only differed less than 0.5-fold (ASH – 672 ± 21.94 to AJK – 966 ± 54.24), the range varied nearly three-fold (AQR – 612 to AJK – 1651).

There was little variation in minimum values (485-526, 41), however, maximum values varied two-fold (1104-2143, 1039).

Lowest annual rainfall – 3 levels of difference: like above except for the exclusion of ASQ in Tukey group **b**.

Mean annual maximum temperature – 4 levels of difference: communities AGH, AHM, AQR, ASH and ASQ are similar (Tukey group **a**), vegetation communities AGH, AHM, AHR, AQR and ASQ are similar in terms of means (group **b**), AGH, AHR, AJK and AQR exhibit similarity (group **c**), while communities AHR, AJK, AQR and ARH share commonality (group **d**).

Means of maximum temperature varied little (ARH – 16.6 ± 0.14 to ASH – 17.6 ± 0.05), however, ranges differed over three-fold (ASH – 16.8-18.1, 1.3 to ARH/AHR – 13.9-18.1, 4.2). Vegetation communities AJK and ARH recorded the lowest maximum temperature of 13.9, while communities AGH, AHM and ASQ recorded the highest maximum temperature, 18.5.

Mean annual minimum temperature – 3 levels of difference: all communities except for AHR and AJK have similar means (group **a**), AGH, AHR, ARH, ASH and ASQ exhibit commonality (Tukey group **b**), and AGH, AHR, AJK and ARH are similar (**c**).

Minimum temperature means varied greater than those of maximum temperature (AJK – 7.9 ± 0.18 to AQR – 9.2 ± 0.24), but ranges varied to just two-fold (AQR – 7.7-10.5, 2.8 to ASQ – 6.2-11.6, 5.4). Lowest minimum temperatures were observed in communities AGH, AHR, AJK, ARH and ASQ (all 6.2), while, highest minimum temperatures were recorded in vegetation communities AHM, ASH and ASQ (each at 11.6).

Highest maximum annual temperature – 3 levels of difference: vegetation communities AGH, AHM, ASH and ASQ are similar in terms of means (group **a**), all communities except for AJK, ARH and ASH display similarity (**b**), while all vegetation communities except for AGH, AHM, ASH and ASQ exhibit commonality (Tukey group **c**).

Means of highest maximum temperature recorded differed little (ARH – 17.5 ± 0.13 to ASH – 18.4 ± 0.18), however, ranges varied just over two-fold (ASH – 17.4-18.9, 1.5 to

AJK/ARH – 15.1-18.9, 3.8). Lowest temperatures were observed in communities AJK and ARH, both 15.1, whereas, the highest temperatures were recorded in AGH, AHM and ASQ, all 19.2.

Lowest minimum annual temperature – 3 levels of difference: all communities except for AGH, AHR and AJK are similar (Tukey group **a**), AGH, AHR, ARH, ASH and ASQ have common means (**b**), and all communities except for AHM, AQR and ASH exhibit similarity (group **c**).

The means of lowest minimum temperature ranged from 6.9 ± 0.18 (AJK) to 8.4 ± 0.26 (AQR), while the ranges varied two-fold (AQR – 6.8-9.7, 2.9 to ASQ – 5.0-10.8, 5.8). The lowest minimum temperatures were observed in vegetation communities AGH, AHR, AJK, ARH and ASQ (5.0), with the highest minimum values recorded in AHM, ASH and ASQ (all 10.8).

Mean highest daily solar exposure – 3 levels of difference: all communities except for AHR, AJK and ARH display similarity (**a**), AGH, AHR and AQR are similar in terms of means (Tukey group **b**), while AHR, AJK, AQR and ARH have similar means (group **c**).

Highest daily solar exposure means varied little between all communities (14.5 ± 0.11 to 15.1 ± 0.09), but ranges differed nearly two-fold (AQR – 13.6-15.7, 2.1 to AJK – 12.5-16.4, 3.9). Lowest values of highest daily solar exposure differed from 12.5 to 13.6 AJK/ARH to all the remainder), while the greatest values varied 15.7 to 16.7 (AQR to AGH/AHM/ASQ).

Mean lowest daily solar exposure – 3 levels of difference: all vegetation communities except for AHR, AJK and ARH exhibit similar means (group **a**), all communities except for AJK and ASH have common means (**b**), and AGH, AHR, AJK and ARH are similar (Tukey group **c**).

Means of lowest daily solar exposure again varied little (ARH – 12.7 ± 0.11 to ASH – 13.3 ± 0.09), however, ranges varied two-fold (AQR – 12.4-14.1, 1.7 to AJK/ARH – 11.0-14.5, 3.5). Lowest values were observed in AJK and ARH (11.0), while greatest values were recorded in AHM, ASH and ASQ (14.6).

Summary

Levels of difference within all climate variables are not high enough for any variable to be classified as an indicator of an individual vegetation community. However, the above results do provide specific climate variable tolerance ranges for individual vegetation communities.

3.4.8 Group indicator plant species

Herein "vegetation community", "community" and "group" are interchangeable and used depending on the context within the text.

Group numbers

The number of plots within each vegetation community are provided in Table 3.25.

Table 3.25: Vegetation community and number and percentage of plots within each group.

Group	AGH	AHM	AHR	AJK	AQR	ARH	ASH	ASQ	Total
No. plots	66	63	33	36	18	57	49	85	407
% of plots	16.22	15.48	8.11	8.85	4.42	14.01	12.04	20.88	100.0

Individual group indicator species

Of the 52 plant species identified throughout all vegetation assessments, 21 species (40.4%) were identified as indicator species ($p<0.01$) for the eight vegetation communities. All groups, except for ASQ, have a combination of species which make up the relative community, with dominant plant species being named first within each group and the remainder species in order of descending dominance (Table 3.26).

Table 3.26: Indicator plant species ($p<0.01$) for each vegetation community (community order alphabetical). **Component A** = *positive predictive value;* **Component B** = *sensitivity* – see section 3.3.5.

Veg group	Plant species	A	B	IndVal	Stat	p-value	
AGH	*Sarcocornia quinqueflora*	0.9952	0.7709	0.7672	0.876	0.001	***
	Austrostipa stipoides	0.7879	0.6364	0.5014	0.708	0.001	***
	Gahnia filum	0.6122	0.5455	0.3340	0.578	0.001	***
	Distichlis distichophylla	0.9165	0.2308	0.2115	0.460	0.002	**
	Disphyma crassifolium	0.9402	0.2022	0.1901	0.436	0.002	**
	Suaeda australis	0.8774	0.1614	0.1416	0.376	0.002	**
	Poa spp.	0.9091	0.1344	0.1222	0.351	0.004	**
	Sarcocornia blackiana	0.9378	0.1292	0.1212	0.348	0.004	**
	Ficinia nodosa	0.9062	0.1301	0.1179	0.343	0.002	**
	Poa labillardierei	0.9445	0.0962	0.0908	0.301	0.003	**

Veg group	Plant species	A	B	IndVal	Stat	p-value	
AHM	*Sarcocornia quinqueflora*	0.9952	0.7709	0.7672	0.876	0.001	***
	Samolus repens	0.8833	0.5136	0.4537	0.674	0.001	***
	Selliera radicans	0.7976	0.3918	0.3125	0.559	0.001	***
	Distichlis distichophylla	0.9165	0.2308	0.2115	0.460	0.002	**
	Hemichroa pentandra	0.9439	0.2209	0.2085	0.457	0.001	***
	Disphyma crassifolium	0.9402	0.2022	0.1901	0.436	0.002	**
	Isolepis cernua	0.6903	0.2029	0.1401	0.374	0.006	**
	Sarcocornia blackiana	0.9378	0.1292	0.1212	0.348	0.004	**
AHR	*Juncus kraussii*	0.8245	0.9762	0.8049	0.897	0.001	***
	Samolus repens	0.8833	0.5136	0.4537	0.674	0.001	***
	Selliera radicans	0.7976	0.3918	0.3125	0.559	0.001	***
	Hemichroa pentandra	0.9439	0.2209	0.2085	0.457	0.001	***
	Apodasmia brownii	0.7406	0.2333	0.1728	0.416	0.002	**
	Suaeda australis	0.8774	0.1614	0.1416	0.376	0.002	**
	Leptinella. longipes	0.6958	0.1889	0.1314	0.363	0.001	***
	Poa spp.	0.9091	0.1344	0.1222	0.351	0.004	**
	Poa labillardierei	0.9445	0.0962	0.0908	0.301	0.003	**
	Baumea juncea	1.0000	0.0606	0.0606	0.246	0.007	**
AJK	*Juncus kraussii*	0.8245	0.9762	0.8049	0.897	0.001	***
	Distichlis distichophylla	0.9165	0.2308	0.2115	0.460	0.002	**
	Apodasmia brownii	0.7406	0.2333	0.1728	0.416	0.002	**
AQR	*Sarcocornia quinqueflora*	0.9952	0.7709	0.7672	0.876	0.001	***
	Samolus repens	0.8833	0.5136	0.4537	0.674	0.001	***
	Selliera radicans	0.7976	0.3918	0.3125	0.559	0.001	***
	Distichlis distichophylla	0.9165	0.2308	0.2115	0.460	0.002	**
	Hemichroa pentandra	0.9439	0.2209	0.2085	0.457	0.001	***
	Suaeda australis	0.8774	0.1614	0.1416	0.376	0.002	**
	Isolepis cernua	0.6903	0.2029	0.1401	0.374	0.006	**
ARH	*Juncus kraussii*	0.8245	0.9762	0.8049	0.897	0.001	***
	Sarcocornia quinqueflora	0.9952	0.7709	0.7672	0.876	0.001	***
	Samolus repens	0.8833	0.5136	0.4537	0.674	0.001	***
	Selliera radicans	0.7976	0.3918	0.3125	0.559	0.001	***
	Distichlis distichophylla	0.9165	0.2308	0.2115	0.460	0.002	**
	Apodasmia brownii	0.7406	0.2333	0.1728	0.416	0.002	**
	Suaeda australis	0.8774	0.1614	0.1416	0.376	0.002	**
	Isolepis cernua	0.6903	0.2029	0.1401	0.374	0.006	**
	Leptinella longipes	0.6958	0.1889	0.1314	0.363	0.001	***
	Poa spp.	0.9091	0.1344	0.1222	0.351	0.004	**
	Ficinia nodosa	0.9062	0.1301	0.1179	0.343	0.002	**
	Poa labillardierei	0.9445	0.0962	0.0908	0.301	0.003	**

Veg group	Plant species	A	B	IndVal	Stat	p-value	
ASH	*Tecticornia arbuscula*	0.8294	1.0000	0.8294	0.911	0.001	***
	Sarcocornia quinqueflora	0.9952	0.7709	0.7672	0.876	0.001	***
	Samolus repens	0.8833	0.5136	0.4537	0.674	0.001	***
	Hemichroa pentandra	0.9439	0.2209	0.2085	0.457	0.001	***
	Disphyma crassifolium	0.9402	0.2022	0.1901	0.436	0.002	**
	Suaeda australis	0.8774	0.1614	0.1416	0.376	0.002	**
	Sarcocornia blackiana	0.9378	0.1292	0.1212	0.348	0.004	**
ASQ	*Sarcocornia quinqueflora*	0.9952	0.7709	0.7672	0.876	0.001	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Section 3.3.5).

Species dominance is based on Components A and B, the Indicator value index is product of the components. Vegetation community ASQ is dominated totally by *S. quinqueflora,* where it is classed as a good indicator (0.9952) for this community and is more than likely to be found in all group members (0.7709), though is not restricted to this community (also found in AGH, AHM, ARH, ASH and AQR) – it is a very common species!). In the case of vegetation community ASH, *T. arbuscula* is a good indicator (0.8294), will be found in all group members (1.000) and is wholly restricted to this community, whereas *S. repens* is a good group indicator (0.8833), it will be found in many group members (0.5136), though importantly, is not restricted to this group (also found in AHM, AHR, ARH and AQR).

On reviewing the species indicator table, vegetation groups ARH and AHR appear identical, as in particular, *J kraussii* is present in both at the top of each respective species list (an excellent indicator – 0.8245, and highly likely found in all group members – 0.9762). However, on closer examination, key plant species are absent in one. Two species – S. *quinqueflora* and *D. distichophylla* – are present in ARH, but absent in AHR, while most of the remaining species found in AHR (e.g. *S, repens, S. radicans, A. brownii* and *S. australis*), are present in ARH. An interesting feature of AHR is the presence of *B. juncea* where it is classified as an excellent indicator (1.000), yet is found sparingly (0.0606), thus suggesting that if this species is observed in the field, it immediately classes that vegetation community as AHR. For simplification, especially in the field, combining both groups 3 and 5 may be a consideration, though the absence of S. *quinqueflora* and *D. distichophylla* in one, and the presence of *B. juncea* in the other, suggest that there is a difference between the two communities and that both should remain as separate vegetation communities.

In comparing vegetation grouping with that identified by Kirkpatrick and Glasby (1981), this study identified eight groups, whereas, Kirkpatrick and Glasby identified seven. In many instances their floristic classification of Tasmanian saltmarshes closely fits that detailed in Table 3.26, though in some cases it does not. For example, community ASQ in this study corresponds with Kirkpatrick and Glasby's group 7 *(S. quinqueflora)*, AQR relates to group 6 (*S. quinqueflora* and *S. repens*), ARH and AHR *(J. kraussii, A. brownii* and *S. repens)* jointly resembles that of group 5 *(J. kraussii, S. quinqueflora, H. pentandra* and *S. repens)*. In the case of community AGH from this study *(S. quinqueflora, A. stipoides, G. filum, D. crassifolium, S. blackiana* and *F. nodosa*), Kirkpatrick and Glasby split this into two groups – group 1 (*A. stipoides, S. repens, S. quinqueflora* and *G. filum*) and group 2 (*A. stipoides, D. crassifolium* and *S. blackiana*).

This study, and that of Kirkpatrick and Glasby, diverge when it comes to key saltmarsh species of *J. kraussii* and *T. arbuscula,* the former identified in a single community (AJK with *A. brownii)*, the latter, as key species in community ASH containing two key herb species, *S. quinqueflora* and *S. repens.* Yet, in both cases, Kirkpatrick and Glasby do not identify individual groups for these key species. This study found that both key species *(J. kraussii* and *T. arbuscula)* do form individual vegetation communities (AJK and ASH) and perhaps the key driver of this may be climate, where, *J. kraussii*, found as a stand-alone group, prefers a wetter cooler climate, and *T. arbuscula*, prefers a dryer, warmer climate (see Figures 3.36 and 3.37, page 80). It is noted that both species can be found together, although it is very uncommon. However, *T. arbuscula* is not found with *J. kraussii* when *J. kraussii* has cover exceeding 25% (cover value >4), again, this has been observed in the field.

3.4.9 Vegetation community key

Each test of the draft (from Training sites data) and proposed (from a combination of Training and Test 1 sites data) vegetation community keys, have identified instances where it was challenging to identify a community due to it being not adequately described, or where a community was incorrectly identified due to miscomprehension of the ranges of cover values 3 and 4.

During vegetation assessments it became apparent that some communities lacked ground cover herbs, for example, at Pipers River, one plot was dominated by *G. filum* at

a cover value 5 (50 to 75%) with the remainder as bare ground, and an absence of ground cover herbs. Obviously, this did not fit in with the key description of "…dominated by graminoids with succulent herbs as ground cover" for AGH (graminoids and herbs). To avoid the creation of one or more vegetation classes (e.g. "graminoids only, with some bare ground"), the key was amended to reflect variations (e.g. the lack of ground cover herbs) that did occur.

It is also important to understand the complexity of cover values, particularly in relation to cover 3 (5 to 25%) and cover 4 (25 to 50%). A species that exhibits, 10% cover, can hardly be viewed as displaying a semi-dominant cover, yet to an untrained observer it is easy to conjure that this is so as the range for cover of 3 extends to 25%. This can also be attributed to a cover 4, where a species can display 30% cover and appear to be a dominant species, as theoretically it could cover up to 50% as it falls in the 25 to 50% range. This complexity can also follow at the top end of the scale when identifying a plant species as cover 5 or 6 and applying a vegetation community classification. It would be straightforward if a single species was present and was attributed a cover value 5, (e.g. *S. quinqueflora*), which would automatically place this community in ASQ. However, if there were two species, such as, *S. quinqueflora* at a cover 5 (50-75% cover) and *J. kraussii* at a cover 6 (>75% cover), both species displaying dominance, into which grouping will this plot fall? Initially, it could be assumed that this is not possible as total cover exceeds 100%, yet structurally, one species *(J. kraussii)* being tussock like, tall and displaying a spreading form (therefore providing a high cover value) and the other a groundcover species, total cover exceeding 100% is entirely possible. However, as the *Juncus* species is the dominant in terms of cover, placement in ARH (rushes and herbs) would be appropriate. Conversely, if the cover values were reversed, *S. quinqueflora* at a cover 6 and *J. kraussii* at a cover 5, placement in the AHR community would be justified as the *Sarcocornia* species is the dominant. Clearly, adequate training is required when assessing vegetation in the field using the Braun-Blanquet method and then classifying communities based on dominance and semi-dominance.

Following a review of community description and application of cover values, the proposed key was modified to remove any anomalies that did and may occur in the future. The final vegetation community key is presented in Table 3.27.

Table 3.27: Final vegetation community key for Tasmanian coastal saltmarsh vegetation communities.

A key to aid the identification and naming of vegetation communities of Tasmania coastal saltmarshes – final

1. Is the vegetation community made up of a single species (e.g. *Juncus kraussii* or *Sarcocornia quinqueflora*), a proportion of bare ground is permitted? ========== go to **2**
or
multiple species, whether a combination of graminoids and herbs, or independently as graminoids and herbs? ========== go to **3**

2. Does the community consist principally of rushes only, with some bare ground (the presence of minor species with a cover value of 2 or less is permitted)? ========== **AJK (Rushes – *Juncus kraussii*)**
or
consist mainly of a succulent herb only with some bare ground (the presence of minor species, whether graminoids or other herbs, with a cover value of 2 or less is permitted)? ========== **ASQ (Succulent herbs – *Sarcocornia quinqueflora*)**

3. Is the vegetation community dominated by graminoids (including rushes)? ====== go to **4**
or
dominated by succulents (shrubs and/or herbs)? ========== go to **6**

4. Is the vegetation community dominated (>50%) by graminoids (e.g. *Austrostipa stipoides*, *Gahnia filum, Juncus kraussii,*) independently or in combination (bare ground is permitted), and/or a presence of succulent herbs (e.g. *Disphyma crassifolium*, *Sarcocornia* spp.) as ground cover? ========== **AGH – Graminoids (D) and Herbs**
or
a mix of rushes and succulent herbs (e.g. *Sarcocornia quinqueflora*, *Samolus repens*)? ========== go to **5**

5. Is the vegetation community made up of rushes as dominant (>50% cover) and succulent herbs as ground cover (bare ground can be present)? ========== **ARH – Rushes (*Juncus kraussii*) (D) and succulent Herbs**
or
is made up of succulent herbs as dominant (>50% cover) and rushes (bare ground can be present) ========== **AHR – succulent Herbs (D) and Rushes**

6. Does the vegetation community contain a mix of the two succulent herbs species, *Sarcocornia quinqueflora* and *Samolus repens,* only? ========== **AQR – succulent herbs (*Sarcocornia quinqueflora* and *Samolus repens*)**
or
succulent shrubs and/or a mix of succulent herbs? ========== go to **7**

7. Is the vegetation community made up of succulent shrubs (>50% cover) only or with the presence of succulent herbs (bare ground can be present)? ========== **ASH – succulent Shrubs (*Tecticornia arbuscula*) and Herbs**
or
a mix of succulent herb species (e.g. *Disphyma crassifolium*, *Sarcocornia* spp., *Wilsonia backhousei*) in any combination? ========== **AHM – Succulent Herbs (Mix)**

3.4.10 Hierarchical vegetation framework

A simple hierarchical vegetation framework for coastal saltmarsh vegetation was constructed based on statistical analysis results and evidence from the field. This is in the form of a manageable classification table that can be used in the field (Table 3.28).

Table 3.28: Suggested hierarchical framework of selected groups of coastal saltmarsh vegetation (based on Faber-Langendoen *et al.* (2012)). **EVC** = ecological vegetation class; the section "sub-group" refers to classification of vegetation communities defined above (see Table 3.26).

← Physiognomy			Floristics →		
Class	**Formation**	**Division**	**EVC**	**Group**	**Sub-group**
Shrub and herb vegetation	Inland shrub and herb vegetation				
	Coastal herb and shrub vegetation	**Saltmarsh**	Rushes and succulent herbs	Rushes: *Juncus kraussii*	Rushes – *J. kraussii*
				Rushes (d) and herbs	Rushes (d) – *J. kraussii* and herbs – mix
				Herbs (d) and rushes	Herbs (d) – *S. repens* and others e.g. *S. quinqueflora, S. radicans* and rushes – *J. kraussii, A. brownii*
			Succulent herbs	Succulent herbs	Succulent herbs – *S. quinqueflora*
					Succulent herbs – *S. quinqueflora* & *S. repens*
					Succulent herbs mix – e.g. *S. quinqueflora, S. repens, S. radicans, H. pentandra* and *D. crassifolium*
			Succulent shrubs and herbs	Succulent shrubs and herbs	Succulent shrubs – *Tecticornia arbuscula* and herbs – e.g. *S. quinqueflora, S. repens*
			Graminoids and succulent herbs	Graminoids (d) and mix of succulent herbs	Graminoids (d) – e.g. *A. stipoides, G. filum* and succulent herbs – mix e.g. *S. quinqueflora, D. crassifolium, S. blackiana*
		Sand-dunes			
		Strand-lines and shingle			
		Soft cliffs			

3.4.11 Revised typology for TASVEG 3.0 groups ASS and ARS

A proposed typology for TASVEG 3.0 codes ASS and ARS, useful at a fine scale in field studies, is outlined below and follows Boon *et al.* (2011) and Department of Primary Industries (2015). As IBRA6.1 regionality defined site selection, the typology follows those region codes.

IBRA6.1 (Sub) Bioregions codes:

FUR02: Flinders

TSE: Tasmanian South East

TSR: Tasmanian Southern Ranges

TWE: Tasmanian West

KIN: King

TNS: Tasmanian Northern Slopes

Conservation status codes used (see de Salas and Baker (2018)):

D: Depleted

E: Endangered

LC: Least Concern

R: Rare

V: Vulnerable

The following typology is ordered by each vegetation community's approximate position in the landscape from the marine interface to the terrestrial interface, and full botanical names are provided for ease of use.

Title: Wet saltmarsh herbland 1 (ASQ)

Distinguishing features: Low saltmarsh zone herbland dominated by a single halophilic, succulent, herb species – *Sarcocornia quinqueflora* – subject to regular tidal inundation (Figure 3.43).

Floristics: Dominated by the succulent herb *Sarcocornia quinqueflora* (>80%) bare ground is non-existent/virtually non-existent.

Structure: Low herbland, generally no higher than 0.3m, but often lower, can appear as "lawns".

Habitat: Low-lying areas, poorly drained soils, subject to regular tidal inundation, most soils to >30cm deep with high levels of organic matter.

Distribution: Widespread from northeast to south east and in far northwest, infrequent on West coasts; non-existent on South coasts. Prevalent in areas of low/medium annual rainfall and a milder climate.

Bioregions: FUR01, TSE, TSR, TWE, KIN and TNS,

Conservation status: LC

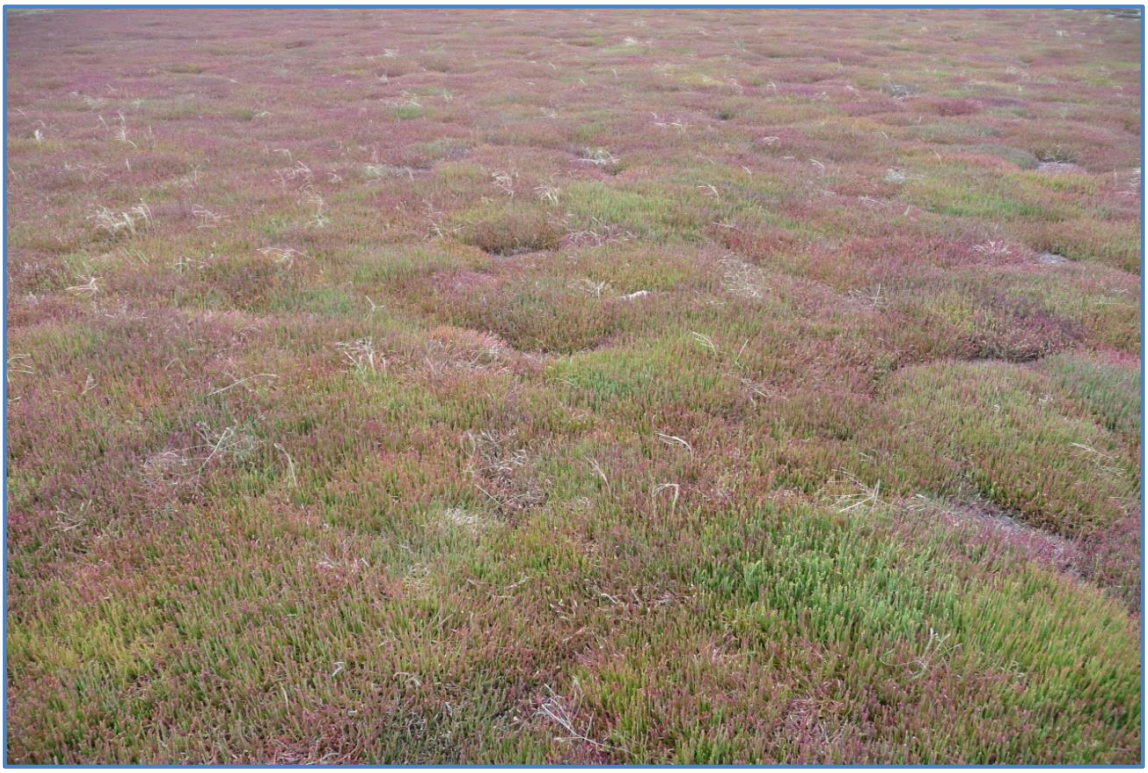


Figure 3.43: Succulent herbs single species – *Sarcocornia quinqueflora*. Site = Burtons Reserve (Cygnet).

Dominant life form cover: 80%

Dominant species	Life form code	Common name
Sarcocornia quinqueflora	H	Beaded glasswort

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	0	0
Herbs and orchids	H	0	0
Tussock grass	TG	1	<5
Non-tussock grass	NTG	0	0
Tiny grass/tiny sedge/tiny lily	TGS	1	<5
Large sedge/rush/sagg/lily	LSR	0	0
Medium to small sedge/rush/sagg/lily	MSR	2	<10
Mosses and lichens	ML	0	0

Organic litter cover: 5%

Secondary species (in order of occurrence)

LF code	Typical understorey species	Common name
MSR	*Puccinellia stricta*	Australian saltmarsh grass
TG	*Poa* spp.	Grasses (mixed)
MSR	*Triglochin striata*	Streaked arrowgrass
TGS	*Isolepis cernua*	Nodding clubsedge

The species listed are typical of this vegetation community, however may not always be present.

Title: Wet saltmarsh herbland 2 (AQR)

Distinguishing features: Low saltmarsh zone herbland dominated by two succulent herb species – *Sarcocornia quinqueflora* and *Samolus repens* – subject to regular tidal inundation (Figure 3.44).

Floristics: Dominated by the succulent herbs *Sarcocornia quinqueflora* and *Samolus repens* (>80%) bare ground can be present, though virtually non-existent.

Structure: Low herbland, generally no higher than 0.3m, but often lower.

Habitat: Low-lying areas, poorly drained soils, at times boggy conditions, subject to regular tidal inundation, most soils to >30cm deep with high levels of organic matter.

Distribution: restricted in range from mid-northeast to southeast (where it is generally located) and found in northwest. Prefers areas of medium average rainfall and with a milder climate.

Bioregions: TSE and KIN

Conservation status: LC

Figure 3.44: Succulent herbs dual species – *Sarcocornia quinqueflora* (insert L) and *Samolus repens* (insert R). Site = Railway Point (Cambridge).

Dominant life form cover: 80%

Dominant species	Life form code	Common name
Sarcocornia quinqueflora	H	Beaded glasswort
Samolus repens	H	Creeping brookweed

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	1	<5
Herbs and orchids	H	2	10
Tussock grass	TG	0	0
Non-tussock grass	NTG	1	<5
Tiny grass/tiny sedge/tiny lily	TGS	1	<5
Large sedge/rush/sagg/lily	LSR	0	0
Medium to small sedge/rush/sagg/lily	MSR	1	<5
Mosses and lichens	ML	0	0

Organic litter cover: 5%

Secondary species (in order of occurrence)

LF code	Typical understorey species	Common name
H	*Selliera radicans*	Shiny swampmat
NTG	*Distichlis distichophylla*	Australian saltgrass
H	*Hemichroa pentandra*	Trailing saltstar
MSR	*Triglochin striata*	Streaked arrowgrass
S	*Suaeda australis*	Australe seablite
TGS	*Isolepis cernua*	Nodding clubsedge

The species listed are typical of this vegetation community, however may not always be present.

Title: Wet saltmarsh herbland 3 (AHM)

Distinguishing features: Low saltmarsh zone herbland dominated by a mix of two to five succulent/semi-succulent herb species subject to regular tidal inundation (Figure 3.45).

Floristics: Dominated by succulent/semi-succulent herbs such as *Sarcocornia quinqueflora, Sarcocornia blackiana, Disphyma crassifolium* and *Wilsonia backhousei*, bare ground is mostly absent.

Structure: Low herbland, generally no higher than 0.3m, but often lower, can appear as "lawns".

Habitat: Low-lying areas, poorly drained soils, subject to regular tidal inundation, most soils to 20cm deep with medium to high levels of organic matter with sandy substrate.

Distribution: Restricted to northeast and east coasts, in areas of medium, average rainfall and a warmer climate.

Bioregions: FUR02 and TSE

Conservation status: LC

Figure 3.45: Mix of succulent herbs e.g. *Sarcocornia quinqueflora* (left), *Sarcocornia blackiana* (right) and *Disphyma crassifolium* (centre bottom, and throughout). Site = Long Point (Moulting Lagoon).

Dominant life form cover: 80%

Dominant species	Life form code	Common name
Sarcocornia quinqueflora	H	Beaded glasswort
Samolus repens	H	Creeping brookweed
Selliera radicans	H	Shiny swampmat
Hemichroa pentandra	H	Trailing saltstar
Disphyma crassifolium	H	Roundleaf pigface

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	0	0
Herbs and orchids	H	1	15
Tussock grass	TG	0	0
Non-tussock grass	NTG	1	<10
Tiny grass/tiny sedge/tiny lily	TGS	1	<5
Large sedge/rush/sagg/lily	LSR	0	0
Medium to small sedge/rush/sagg/lily	MSR	0	0
Mosses and lichens	ML	0	0

Organic litter cover: 5%

Secondary species (by order of occurrence)

LF code	Typical understorey species	Common name
NTG	*Distichlis distichophylla*	Australian saltgrass
TGS	*Isolepis cernua*	Nodding clubsedge
H	*Sarcocornia blackiana*	Thickhead glasswort

The species listed are typical of this vegetation community, however may not always be present.

Title: Rushland (AJK)

Distinguishing features: Tall rushland consisting of only reeds or dominated by reeds (generally greater than 75% cover, though can be lower) occupying low and mid lying areas of coastal saltmarsh subject to regular tidal inundation (Figure 3.46).

Floristics: Species poor, dominated by single species – *Juncus kraussii* – although *Apodasmia brownii* can be present in some cases, with some bare ground.

Structure: Tall rushland, generally above 1m tall, can be in stands up to 2m in areas of lower salinity often due to higher rainfall and brackish water.

Habitat: Low to mid lying areas, often poorly drained, subject to regular tidal inundation, areas subject to waterlogging, mostly, but not always, in soils high in organic matter.

Distribution: Widespread, found in most areas of coastal bioregions except for FUR and TSE, although occasionally found in areas of brackish water. Mostly prefers areas of higher than average rainfall and a cooler climate.

Bioregions: TSE, TSR, TWE, KIN and TNS

Conservation status: LC

Figure 3.46: Rushland dominated (>75% cover or a cover score of 6) by *Juncus kraussii*. Site = Hastings Bay (Hastings).

Dominant life form cover: 75%

Dominant species	Life form code	Common name
Juncus kraussii	LSR	Sea rush
Distichlis distichophylla	NTG	Australian saltgrass
Apodasmia brownii	LSR	Coarse twinerush

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	0	0
Herbs and orchids	H	0	0
Tussock grass	TG	0	0
Non-tussock grass	NTG	0	0
Tiny grass/tiny sedge/tiny lily	TGS	0	0
Large sedge/rush/sagg/lily	LSR	0	0
Medium to small sedge/rush/sagg/lily	MSR	0	0
Mosses and lichens	ML	0	0

Organic litter cover: 10%

Secondary species (in order of occurrence)

LF code	Typical understorey species	Common name

The species listed are typical of this vegetation community, however may not always be present.

Title: Rushland and herbland (ARH)

Distinguishing features: Medium rushland consisting of a mix of reeds (>50% cover) and herbs with reeds, occupying mid-lying areas of coastal saltmarsh subject to infrequent tidal inundation (Figure 3.47).

Floristics: Dominated by *Juncus kraussii*, with *Apodasmia brownii* as a secondary rush species, and ground cover of succulent/semi-succulent herbs e.g. *Sarcocornia quinqueflora, Samolus repens* and *Selliera radicans*, with some bare ground.

Structure: Medium rushland, generally 0.75m tall, some stands to 1m tall. Herbland to 0.3m, but often lower.

Habitat: Mid-lying areas, superficially well-drained, subject to infrequent tidal inundation, areas subject to some waterlogging, mostly soils high in organic matter.

Distribution: Widespread, found in most areas of coastal bioregions except for Furneaux. Prefers areas of average to high rainfall and a cooler climate.

Bioregions: TSE, TSR, TWE, KIN and TNS

Conservation status: LC

Figure 3.47: Rushland/herbland, dominated by reeds (>50% cover) – *Juncus kraussii/Apodasmia brownii* – with ground cover succulent herbs e.g. *Sarcocornia quinqueflora, Sarcocornia blackiana, Samolus repens, Selliera radicans*, and occasionally *Hemichroa pentandra.* Site = 5 Mile Beach (Llanherne).

Dominant life form cover: 60%

Dominant species	Life form code	Common name
Juncus kraussii	LSR	Sea rush
Sarcocornia quinqueflora	H	Beaded glasswort
Samolus repens	H	Creeping brookweed
Selliera radicans	H	Shiny swampmat
Apodasmia brownii	LSR	Coarse twinerush

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	1	<10
Herbs and orchids	H	1	<5
Tussock grass	TG	1	10
Non-tussock grass	NTG	3	10
Tiny grass/tiny sedge/tiny lily	TGS	1	<5
Large sedge/rush/sagg/lily	LSR	1	<10
Medium to small sedge/rush/sagg/lily	MSR	0	0
Mosses and lichens	ML	0	0

Organic litter cover: 10%

Secondary species (in order of occurrence)

LF code	Typical understorey species	Common name
NTG	*Distichlis distichophylla*	Australian saltgrass
S	*Suaeda australis*	Australe seablite
TGS	*Isolepis cernua*	Nodding clubsedge
H	*Leptinella longipes*	Coast buttons
NTG	*Poa* spp.	Grasses
LSR	*Ficinia nodosa*	Knobby clubsedge
TG	*Poa labillardierei*	Silver tussockgrass

The species listed are typical of this vegetation community, however may not always be present.

Title: Wet saltmarsh shrubland (ASH)

Distinguishing features: Shrubland dominated by halophytic succulent/semi-succulent shrubs and herbs species subject to regular/spasmodic tidal inundation, often with bare ground (Figure 3.48).

Floristics: Dominated by succulent shrubs – *Tecticornia arbuscula* – herbs, such as *Sarcocornia quinqueflora, Samolus repens* and *Hemichroa pentandra* as ground cover species, bare ground often presents under *Tecticornia arbuscula.*

Structure: Shrubland to 1.5m, occasionally to 2m when existent on levee banks, low herbs, generally no higher than 0.3m, but often lower.

Habitat: Low- to mid-lying areas, poorly drained soils, though can appear to be well drained, subject to regular/infrequent tidal inundation; most soils are shallow with low to medium levels of organic matter, composition often high in sand.

Distribution: Ranges from northeast to southeast and found in northwest; higher prevalence in warmer/drier areas.

Bioregions: FUR02, TSE and KIN

Conservation status: LC

Figure 3.48: Wet saltmarsh shrubland dominated by *Tecticornia arbuscula* with *Sarcocornia quinqueflora* and *Hemichroa pentandra* as groundcover. Site = Cremorne Bay (Sandford).

Dominant life form cover: 80%

Dominant species	Life form code	Common name
Tecticornia arbuscula	S	Shrubby glasswort
Sarcocornia quinqueflora	H	Beaded glasswort
Samolus repens	H	Creeping brookweed
Hemichroa pentandra	H	Trailing saltstar

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	1	<10
Herbs and orchids	H	3	20
Tussock grass	TG	0	0
Non-tussock grass	NTG	0	0
Tiny grass/tiny sedge/tiny lily	TGS	0	0
Large sedge/rush/sagg/lily	LSR	0	0
Medium to small sedge/rush/sagg/lily	MSR	0	0
Mosses and lichens	ML	0	0

Organic litter cover: 15%

Secondary species (by order of occurrence)

LF code	Typical understorey species	Common name
H	*Disphyma crassifolium*	Roundleaf pigface
S	*Suaeda australis*	Austral seablite
H	*Sarcocornia blackiana*	Thickhead glasswort

The species listed are typical of this vegetation community, however may not always be present.

Title: Coastal herbland and rushland (AHR)

Distinguishing features: Herbland dominated (>50%) by succulent/semi-succulent herb species with rushes as associated species (<50%), subject to aerobic salt spray and to inundation during high rainfall periods, often with some bare ground (Figure 3.49).

Floristics: Dominated by succulent/semi succulent herbs, such as, *Samolus repens, Selliera radicans* and to a lesser extent *Sarcocornia quinqueflora,* associated with *Juncus kraussii* and lesser extent *Apodasmia brownii.*

Structure: Herbland to 0.3m or lower, rushland to 0.5m, rarely to 1m.

Habitat: Upper-lying areas, medium drained soils, though can appear to be well drained, inundation during heavy rainfall periods, generally above tidal influence, most soils are shallow with low to medium levels of organic matter, composition often high in sand with sand substrate.

Distribution: Widespread, found in all bioregions, prevalent in areas of medium average rainfall and temperature.

Bioregions: FUR02, TSE, TSR, TWE, KIN and TNS

Conservation status: LC

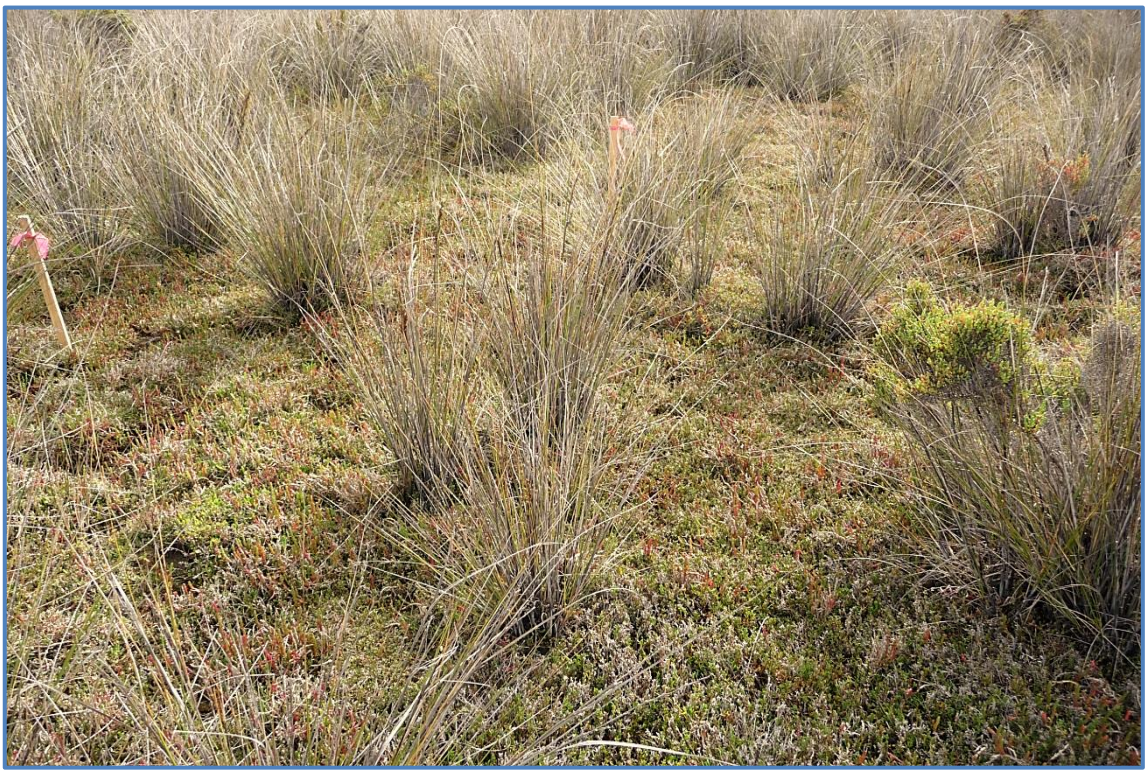


Figure 3.49: Coastal herbland and rushland dominated by herbs such as *Samolus repens* and *Selliera radicans,* associated with *Juncus kraussii*. Site = Long Point (Moulting Lagoon).

Dominant life form cover: 60%

Dominant species	Life form code	Common name
Juncus kraussii	LSR	Sea rush
Samolus repens	H	Creeping brookweed
Selliera radicans	H	Shiny swampmat
Hemichroa pentandra	H	Trailing saltstar
Apodasmia brownii	LSR	Coarse twinerush

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	1	5
Herbs and orchids	H	1	<5
Tussock grass	TG	1	10
Non-tussock grass	NTG	2	10
Tiny grass/tiny sedge/tiny lily	TGS	0	0
Large sedge/rush/sagg/lily	LSR	0	0
Medium to small sedge/rush/sagg/lily	MSR	1	5
Mosses and lichens	ML	0	0

Organic litter cover: 10%

Secondary species (in order of occurrence)

LF code	Typical understorey species	Common name
S	*Suaeda australis*	Austral seablite
H	*Leptinella longipes*	Coast buttons
NTG	*Poa* spp.	Grasses
TG	*Poa labillardierei*	Silver tussockgrass
MSR	*Baumea juncea*	Bare twigsedge

The species listed are typical of this vegetation community, however may not always be present.

Title: Coastal tussock saltmarsh (AGH)

Distinguishing features: Upper saltmarsh zone dominated by saline graminoids with ground cover succulent/semi-succulent herbs subject to aeolian salt spray (Figure 3.50).

Floristics: Dominated by graminoids, such as, *Austrostipa stipoides, Gahnia filum* and *Distichlis distichophylla,* and ground cover of succulent/semi-succulent herbs, for example, *Sarcocornia quinqueflora, Sarcocornia blackiana* and *Disphyma crassifolium* with some bare ground.

Structure: Medium grassland, generally 0.75m tall, some stands to 1m tall, generally in tussocks/clumps, herbs to 0.3m, but often lower.

Habitat: Upper-lying areas, often well-drained except during high rainfall events, subject to aeolian salt spray, mostly shallow soils medium levels of organic matter.

Distribution: Found from northeast to southeast, west coast and northwest in areas of medium to low average rainfall and a warmer climate.

Bioregions: FUR02, TSE, TWE and KIN

Conservation status: LC

Figure 3.50: Coastal tussock saltmarsh, dominated by graminoids (>50% cover) e.g. *Austrostipa stipoides* and *Gahnia filum*, ground cover succulent herbs e.g. *Sarcocornia quinqueflora, Sarcocornia blackiana* and *Disphyma crassifolium*. Site = Long Point (Moulting Lagoon).

Dominant life form cover: 60%

Dominant species	Life form code	Common name
Sarcocornia quinqueflora	H	Beaded glasswort
Austrostipa stipoides	TG	Coast speargrass
Gahnia filum	TG	Chaffy sawsedge

Understorey:

Life forms	LF code	No. of species	% cover
Shrub	S	1	10
Herbs and orchids	H	2	15
Tussock grass	TG	1	5
Non-tussock grass	NTG	3	10
Tiny grass/tiny sedge/tiny lily	TGS	0	0
Large sedge/rush/sagg/lily	LSR	1	5
Medium to small sedge/rush/sagg/lily	MSR	0	0
Mosses and lichens	ML	0	0

Organic litter cover: 15%

Secondary species

LF code	Typical understorey species	Common name
NTG	*Distichlis distichophylla*	Australian saltgrass
H	*Disphyma crassifolium*	Roundleaf pigface
S	*Suaeda australis*	Australe seablite
NTG	*Poa* spp.	Grasses
H	*Sarcocornia blackiana*	Thickhead glasswort
LSR	*Ficinia nodosa*	Knobby clubsedge
TG	*Poa labillardierei*	Silver tussockgrass

The species listed are typical of this vegetation community, however may not always be present.

3.4.12 Alignment to previous studies

Botanical names in this section have been updated and aligned to current nomenclature of de Salas and Baker (2018) from those originally published.

Continental/landscape scale – Bridgewater and Cresswell (2003)

Previous work by Bridgewater and Cresswell (2003) at the IBRA bioregional level, identified a main group of saltmarsh plants (Group I: *Tecticornia arbuscula-Juncus kraussii* group) that ranged along Australia's southern coastline including Tasmania. This group was divided into two sub-groups that referenced (at that time, 2003) Tasmania's saltmarsh plants: I.1 *Austrostipa stipoides-Selliera radicans* confined the west coast, and I.2: *Austrostipa stipoides-Lachnagrostis billardieri*, confined to eastern Tasmania (and southeast Australia to northern NSW) (see Table 3.2, page 3.8). Although this work provided saltmarsh plant distribution at a landscape scale, it appears to have failed to capture plant species ranges that are now found.

The Group I identifier – *Tecticornia arbuscula-Juncus kraussii*, has, in a fashion, correctly concluded the presence of succulents *(T. arbuscula)* and graminoids *(J. kraussii)* within the Tasmanian context. However, when it comes to the two sub-groups, key plant species, such as *S. quinqueflora, S. repens, D. distichophylla,* are missing (see Table 3.18, page 3.65 for list of species). The notion of Bridgewater and Cresswell (2003) that climate variables play a role in species distribution, is correct, as this study has found that many species are confined by wet/dry and warm/cool conditions (see Figures 3.33 and 3.34, page 3.78). As work by Deil (2000) and Fariña *et al.* (2018) have demonstrated, and Bridgewater and Cresswell (2003) have acknowledged, there is a strong link between geographical distribution of plant species and climatic variations. Therefore, maintaining this concept is important when redefining saltmarsh plant distribution from a landscape viewpoint. A suggested refinement/update to the earlier Bridgewater and Cresswell (2003) model is proposed in Table 3.29.

The main Group I nomenclature is maintained as this best encapsulates the presence of the range of succulents and graminoids in Tasmanian coastal saltmarshes. The sub-groups have been increased to three and the labels altered to best reflect the key plant species within each sub-group. The sub-groups best characterise the climatic zones found around the Tasmanian coastline and the plant species found in each zone. The

increase in sub-group numbers to three is justified considering the nMDS ordination presented in Figures 3.33 and 3.34 (page 3.78), as field observations strongly support this finding.

Table 3.29: A refinement to the Bridgewater and Cresswell (2003) model of a landscape scale distribution of saltmarsh plants.

Group	Sub-group	Range	Species
I. Sclerostegia arbuscula- Juncus kraussii		Southern Australia coastline and Tasmania	
	I.1 *Juncus kraussii-Apodasmia brownii*	Generally confined to southern and western Tasmania	*Juncus kraussii, Apodasmia brownii, Selliera radicans, Schoenus nitens, Atriplex prostrata*
	I.2 *Tecticornia arbuscula-Austrostipa stipoides*	Generally confined to north-eastern and eastern Tasmania	*Tecticornia arbuscula, Austrostipa stipoides, Gahnia filum, Sarcocornia blackiana, Suaeda australis, Wilsonia backhousei, Distichlis distichophylla*
	I.3 *Sarcocornia quinqueflora-Samolus repens*	Generally confined to northern, eastern and south eastern Tasmania	*Sarcocornia quinqueflora, Samolus repens, Disphyma crassifolium, Hemichroa pentandra, Triglochin striata*

Local/fine scale – Kirkpatrick and Glasby (1981)

Similar to group indicator species, the use of structural forms by Kirkpatrick and Glasby (1981) to define Tasmanian saltmarsh communities corresponds well with that proposed in Table 3.25 (pages 3.85-3.87) with some modification (Table 3.30).

Table 3.30: Comparison of structural communities between Kirkpatrick and Glasby (1981) and this study.

Kirkpatrick and Glasby (1981)		This study	
Structural community	**Key species**	**Structural community**	**Key species**
Succulent shrubs	*Tecticornia arbuscula* *Sarcocornia quinqueflora* *Sarcocornia blackiana* *Hemichroa pentandra*	Succulent shrubs and herbs	*Tecticornia arbuscula* *Sarcocornia quinqueflora*
Herbs	*Wilsonia backhousei* *Samolus repens* *Schoenus nitens*	Succulent herbs	*Sarcocornia quinqueflora* *Samolus repens*
Grasses	*Austrostipa stipoides* *Distichlis distichophylla*	Graminoids and succulent herbs	*Austrostipa stipoides* *Ficinia nodosa* *Disphyma crassifolium*
Sedges and rushes	*Gahnia filum* *Juncus kraussii* *Apodasmia brownii*	Rushes and succulent herbs	*Juncus kraussii* *Gahnia filum* *Samolus repens* *Sarcocornia quinqueflora* *Selliera radicans*

Further, Kirkpatrick and Glasby, extended structural communities to a somewhat extremely fine scale, where 15 communities have been defined principally by individual species, for example, the community dominated by succulent species has been further divided to six sub-groups as follows:

1. *Tecticornia arbuscula* – open heath (also closed-heath and low shrubland);
2. *Suaeda australis* – open to closed heath;
3. *Sarcocornia quinqueflora* – low open-heath;
4. *Sarcocornia blackiana* – low open-heath;
5. *Hemichroa pentandra* – low open- to closed-heath; and
6. *Disphyma crassifolium* – low open-heath.

It is acceptable that the above individual species do at times form individual communities, however, this study found that in most cases, two or more of the above listed species are found in combination, forming an individual community of mixed species. Based on Kirkpatrick and Glasby's structural community succulent species, divided to six sub-groups, this study found it was more common that this community could be divided into three sub-groups as follows:

1. Shrubland – *Tecticornia arbuscula, Sarcocornia quinqueflora, Hemichroa pentandra, Disphyma crassifolium, Suaeda australis*;
2. Herbland 1 – *Sarcocornia quinqueflora* – evident as a single species community; and
3. Herbland 3 (a mixed herb community) – *Sarcocornia quinqueflora, Sarcocornia blackiana, Hemichroa pentandra, Disphyma crassifolium*.

Similarly, the above can be applied to Kirkpatrick and Glasby's community dominated by sedges and herbs, which has been divided into three sub-groups:

1. *Gahnia filum* – tussock sedgeland to closed-tussock sedgeland;
2. *Juncus kraussii* – open-rushland; and
3. *Apodasmia brownii* – open-rushland.

Again, it is acceptable that the above individual species can at times form individual communities, but this study found that in most cases, two or more of the above listed

species can be found in combination, forming communities of mixed species. Based on Kirkpatrick and Glasby's structural community sedges and herbs, divided to three sub-groups, this study found it was more common that the community could be divided into two sub-groups as follows:

1. Rushland – *Juncus kraussii,* as an individual species, or in combination with *Apodasmia brownii;* and
2. Tussock saltmarsh – where *Gahnia filum* is a recorded as a dominant species (with *Austrostipa stipoides* and others).

It is acknowledged that the results of Kirkpatrick and Glasby (1981), where dividing saltmarsh communities to 15 levels, can be beneficial. However, how often will each of the individual 15 communities be observed in the field, and ultimately, does it reflect the real world (Wildi 2013)? This study shows that in numerous instances, plant species association/combination occurs very frequently and is significant, and that, in the words of Kirkpatrick and Glasby, "species occur together significantly more often than could be expected by chance" (page 12). In light of this, it is more appropriate and beneficial to acknowledge the real-world status of species combinations and have this reflected in vegetation groupings.

3.4.13 Natural regionalisation and vegetation communities

From herein, the use of the term IBRA, implies version 6.1, IMCRA implies version 3.3, BOM coast refers to BOM coastal districts, Geographic represents those geographical regions proposed by Edgar *et al.* (1999), and Estuarine refers to the coastal marine classes also proposed by Edgar *et al.* (1999). The term community/communities implies vegetation community/communities.

Field-plots by regionalisation

The concentration of field-plots by region by regionalisation is presented in Table 3.31. Data are interpreted by column, therefore a focus on regionalisation.

Table 3.31: Number and percentage (%) of plots by region by regionalisation. Values (number of plots and percentage) in **blue** are highest (≥30%), those in **red** are middle of range (20-29%), and those in **green** are lowest (10-19%, generally <10% excluded) within each individual regionalisation. Within each regionalisation, region order begins at Flinders/ Furneaux and continues in a clockwise fashion.

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	71	17	FLI	9	2	EoF	10	2	FUR	9	2	BLSE	41	10	
TSE	193	47	FRE	117	29	Banks	14	3	EAST	126	31	HS_Lag	46	11	
TSR	62	15	BRU	159	39	upperEAST	33	8	SE	160	39	LMTR	22	5	
TWE	25	6	DAV	17	4	lowerEAST	93	23	SOUTH	7	2	LOMR	7	2	
KIN	51	13	FRA	29	7	SE	7	2	WEST	29	7	Mar_In	189	46	
TNS	5	1	OTW	14	3	SEinshore	147	36	KING	14	3	MTDRV	51	13	
			BGS	62	15	SW	4	1	NWEST	37	9	Open	51	13	
						WEST	21	5	eastNORTH	25	6				
						NWEST	44	11							
						NORTH	34	8							
	407	100		407	100		407	100		407	100		407	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 407 plots), 2% of the plots are in region FLI, **29% in region FRE**, **39% in region BRU**, 4% in region DAV, 7% in region FRA, 3% in region OTW, and **15% in region BGS**.
IBRA region codes: **FUR** = Flinders (FUR01), **KIN** = King, **TNS** = Tasmanian Northern Slopes, **TSE** = Tasmanian South East, **TSR** = Tasmanian Southern Ranges, **TWE** = Tasmanian West.

IMCRA region codes: **BGS** = Boags, **BRU** = Bruny, **DAV** = Davey, **FLI** = Flinders, **FRA** = Franklin, **FRE** = Freycinet, **OTW** = Otway.

BOM coastal district codes: **Banks** = Banks Strait, **EoF** = East of Flinders Island, **lowerEAST** = Lower East Coast, **NORTH** = Central North Coast, **SE** = Southeast Coast, **SEinshore** = Southeast inshore, **SW** = Southwest Coast, **upperEAST** = Upper East Coast, **WEST** = Central West Coast. Terminology follows BOM (2017).

Geographic region codes: **EAST** = East coast, **eastNORTH** = East (section) north coast, **FUR** = Furneaux Group, **KIN** = King Island, **NWEST** = North west, **SE** = South east, **SOUTH** = South coast, **WEST** = West Coast. Terminology follows Edgar (1999).

Estuarine group codes: **BLSE** = barred, low salinity estuary, **HS_Lag** = hypersaline lagoon, **LMTR** = large meso-tidal river, **LOMR** = large, open micro-tidal river, **Mar_In** = marine inlet, **MTDRV** = micro-tidal drowned river valley, **Open** = open estuary. Terminology follows Edgar (1999).

Field plots were recorded in each region (within each regionalisation), however, several regions contain less than 10 plots. The highest concentration of plots occurred in regions positioned on the east and southeast coast (e.g. IBRA regions TSE, TSR – total 62%, IMCRA regions FRE, BRU – total 68%). This reflects the large number of saltmarshes found on the Tasmania's east coast, which is a relatively protected environment and accessible. In contrast, the lowest number of plots occurred in regions of the south, west and some northern coasts (e.g. BOM coast region SW – 1%, Geographic region SOUTH – 2%), which mirrors the paucity of coastal saltmarshes on

the island's exposed south and west coasts as well as the general inaccessibility of the area. In respect of Estuarine groups, most plots were in marine inlets (46%), while the least number were positioned in LMTR (large meso-tidal rivers) (5%) and LOMR (large open micro-tidal rivers) (2%).

Vegetation group by regionalisation

The number of field plots by vegetation community within each individual region are presented in Tables 3.32 to 3.39.

Vegetation community AGH (graminoids and herbs)

Table 3.32: Number and percentage (%) of plots by vegetation community AGH by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	8	12	FLI	1	2	EoF	0	0	FUR	1	2	BLSE	6	9	
TSE	37	56	FRE	25	38	Banks	0	0	EAST	25	38	HS_Lag	6	9	
TSR	8	12	BRU	24	36	upperEAST	5	8	SE	24	36	LMTR	4	6	
TWE	3	5	DAV	0	0	lowerEAST	21	32	SOUTH	0	0	LOMR	2	3	
KIN	9	14	FRA	5	8	SE	0	0	WEST	5	8	Mar_In	34	52	
TNS	1	2	OTW	2	3	SEinshore	23	35	KING	2	3	MTDRV	8	12	
			BGS	9	14	SW	0	0	NWEST	6	9	Open	6	9	
						WEST	3	5	eastNORTH	3	5				
						NWEST	7	11							
						NORTH	7	11							
	66	100		66	100		66	100		66	100		66	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 66 plots), 2% of the plots are in region FLI, **38% in region FRE**, **36% in region BRU**, 0% in region DAV, 8% in region FRA, 3% in region OTW, and **14% in region BGS**.

Vegetation community AGH was found in each region of just two regionalisations, IBRA and Estuarine, although some regions exhibited low presence (in IBRA, TNS 2%, TSR and TWE 5%, in Estuarine, LOMR 3%). The community was missing from four regions (EoF, Banks, SE and SW) in BOM coast, yet had a primary dominance (≥30%) in SEinshore (35%) and lowerEAST (32%). High primary dominance was observed in the IBRA region TSE (56%), which at a first pass may suggest that this

region is a good indicator of community AGH. Primary dominance was also noted in IMCRA regions FRE (38%) and BRU (36%), BOM coast districts SE inshore (35%) and lowerEAST (32%), Geographic regions EAST (38%) and SE (36%). Each of the pairs of regions in each regionalisation adjoin and all are on the eastern seaboard of the State. Community AGH was highly dominant in the Estuarine class Mar_In at 52%, suggesting that AGH prefers a protected environment, yet open to the sea. Secondary dominance (20-29%) was not displayed within any region, while several regions displayed tertiary dominance (10-19%), most exhibiting low presence (e.g. IMCRA, FLI, 2%; Geographic, FUR, 2%). The data (Table 3.32) does suggest that AGH is an east and northern coast dominant vegetation community with little to no presence on the State's south and west coasts.

Vegetation community AHM (herbs mixed)

Table 3.33: Number and percentage (%) of plots by vegetation community AHM by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	17	27	FLI	2	3	EoF	3	5	FUR	2	3	BLSE	6	10	
TSE	31	49	FRE	23	37	Banks	4	6	EAST	27	43	HS_Lag	11	17	
TSR	5	8	BRU	22	35	upperEAST	9	14	SE	18	29	LMTR	3	5	
TWE	4	6	DAV	0	0	lowerEAST	17	27	SOUTH	0	0	LOMR	2	3	
KIN	6	10	FRA	6	10	SE	0	0	WEST	6	10	Mar_In	33	52	
TNS	0	0	OTW	0	0	SEinshore	15	24	KING	0	0	MTDRV	4	6	
			BGS	10	16	SW	0	0	NWEST	5	8	Open	4	6	
						WEST	4	6	eastNORTH	5	8				
						NWEST	5	8							
						NORTH	6	10							
	63	100		63	100		63	100		63	100		63	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 63 plots), 3% of the plots are in region FLI, **37% in region FRE**, **35% in region BRU**, 0% in region DAV, **10% in region FRA**, 0% in region OTW, and **16% in region BGS**.

Community AHM was found in all Estuarine classes, however, was absent from at least one region in each of the remaining regionalisations. AHM absence was noted in IBRA (TNS), IMCRA (DAV and OTW), BOM coast (SE and SW) and Geographic (SOUTH

and KING). It was also recorded as low incidence in several regions, for example, IMCRA (FLI, 3%), Geographic (FUR, 3%) and Estuarine (LOMR, 3%). High primary dominance (≥30%) was observed in the Estuarine class Mar_In (52%) and IBRA region TSE (49%) which may suggest that both regions are useful indicators of community AHM. Primary dominance was also noted in IMCRA regions FRE (37%) and BRU (35%) and Geographic regions EAST (43%). Again, similar to AGH, each region in each regionalisation are on the eastern seaboard of the State. Secondary dominance (20-29%)was displayed in IBRA (FUR, 27%), BOM coast (lowerEAST, 27% and SEinshore, 24%) and Geographic (SE, 29%), while few regions displayed tertiary dominance (10-19%), most exhibiting low presence. Analogous to AGH, the data (Table 3.33) does suggest that AHM is an east and northern coast dominant vegetation community with little to no presence on the State's south and west coasts. The results also imply that both communities (AGH and AHM) have an association in the landscape displaying primary dominance in identical regions.

Vegetation community AHR (herbs and rushes)

Table 3.34: Number and percentage (%) of plots by vegetation community AHR by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			**IMCRA**			**BOM coast**			**Geographic**			**Estuarine**			
Region	**Plot**	**%**	**Region**	**Plot**	**%**	**Region**	**Plot**	**%**	**Region**	**Plot**	**%**	**Region**	**Plot**	**%**
FUR	**6**	**18**	FLI	1	3	EoF	2	6	FUR	1	3	BLSE	2	6
TSE	**10**	**30**	FRE	**7**	**21**	Banks	0	0	EAST	**7**	**21**	HS_Lag	3	9
TSR	**10**	**30**	BRU	**16**	**48**	upperEAST	3	9	SE	**17**	**52**	LMTR	2	6
TWE	**4**	**12**	DAV	1	3	lowerEAST	**4**	**12**	SOUTH	0	0	LOMR	0	0
KIN	2	6	FRA	**4**	**12**	SE	0	0	WEST	**4**	**12**	Mar_In	**12**	**36**
TNS	1	3	OTW	1	3	SEinshore	**16**	**48**	KING	1	3	MTDRV	**10**	**30**
			BGS	3	9	SW	0	0	NWEST	2	6	Open	**4**	**12**
						WEST	**4**	**12**	eastNORTH	1	3			
						NWEST	2	6						
						NORTH	2	6						
	33	100		33	100		33	100		33	100		33	100

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 33 plots), 3% of the plots are in region FLI, **21% in region FRE**, **48% in region BRU**, 3% in region DAV, **12% in region FRA**, 3% in region OTW, and 9% in region BGS.

Vegetation community AHR was found in each region of just two regionalisations, IBRA and IMCRA, although some regions exhibited low presence (IBRA, TNS 3%; IMCRA, FLI, DAV and OTW, all 3%). The community was absent in three regions in BOM coast (Banks, SE and SW), yet had a high primary dominance in SEinshore (48%). AHR was also absent in Geographic (SOUTH) and Estuarine (LOMR). High primary dominance of AHR was observed in Geographic (SE – 52%), IMCRA (BRU) and BOM coast (SEinshore) (both at 48%), which may suggest that the three regions are good indicators of community AGH. IBRA regions TSE and TSR (both 33%) and Estuarine classes Mar_In and MTDRV (36 and 30%) also displayed primary dominance (≥30%) of AHR. The observed primary dominance in IBRA, IMCRA, BOM coast and Geographic regions again suggest that AHR prefers the east and southeast regions of the State. This can also be said for Mar_In in Estuarine classification, where the previous vegetation communities appeared to also dominate. Secondary dominance (20-29%) was displayed in IMCRA (FRE, 21%) and Geographic (EAST, 21%), all eastern regions. Tertiary dominance (10-19%) was observed in IBRA (FUR, 18%, TWE, 12%), IMCRA (FRA, 12%) and Geographic (WEST, 12%), three of these regions (TWE, FRA, WEST) are situated on Tasmania's west coast, and the remaining region (FUR) in the Furneaux Islands. The data (Table 3.34) suggests that AHR is an east and southeast coast dominant vegetation community, however there is some presence on the State's west coast, which implies that community AHR is not solely restricted in a geographical sense as are AGH and AHM.

Vegetation community AJK (Juncus kraussii)

Table 3.35: Number and percentage (%) of plots by vegetation community AJK by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	2	6	FLI	0	0	EoF	0	0	FUR	0	0	BLSE	2	6	
TSE	**10**	**28**	FRE	**4**	**11**	Banks	0	0	EAST	**4**	**11**	HS_Lag	1	3	
TSR	**13**	**36**	BRU	**12**	**33**	upperEAST	1	3	SE	**20**	**56**	LMTR	**5**	**14**	
TWE	**4**	**11**	DAV	**9**	**25**	lowerEAST	**4**	**11**	SOUTH	1	3	LOMR	0	0	
KIN	**4**	**11**	FRA	3	8	SE	1	3	WEST	3	8	Mar_In	**11**	**31**	
TNS	3	8	OTW	0	0	SEinshore	**18**	**50**	KING	0	0	MTDRV	**5**	**14**	
			BGS	**8**	**22**	SW	1	3	NWEST	**7**	**19**	Open	**12**	**33**	
						WEST	3	8	eastNORTH	1	3				
						NWEST	2	6							
						NORTH	**6**	**17**							
	36	100		36	100		36	100		36	100		36	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 66 plots), 0% of the plots are in region FLI, **11% in region FRE**, **33% in region BRU**, **25% in region DAV**, 8% in region FRA, 0% in region OTW, and **22% in region BGS**.

Community AJK was found in every region of just one regionalisations, IBRA, although region FUR exhibited very low presence (6%). The community was missing from regions in IMCRA (FLI and OTW), BOM coast (EoF and Banks), Geographic (FUR and KING) and Estuarine (LOMR). High primary dominance was observed in the Geographic (SE, 56%) and BOM coast (SEinshore 50%) which may imply that the two regions are good indicators of community AJK. Primary dominance (≥30%) was also noted in IBRA (TSR, 36%), IMCRA (BRU (33%) and Estuarine (Open, 33% and Mar_In, 31%), all regions in the Tasmanian east and south east. Secondary dominance (20-29%) was observed in IBRA (TSE, 28%), IMCRA (DAV, 25% and BGS, 22%), while tertiary dominance (10-19%) was mainly found in regions of the west, northwest (including King Island) and northern coasts. Dominance in Estuarine classification suggest preference for open shores (Open) and marine inlets (Mar_In). With prime dominance still on the State's east and southeast, AJK displays an association with the previous vegetation communities of AGH, AHM and AHR.

Vegetation community AQR (S. quinqueflora and S. repens)

Table 3.36: Number and percentage (%) of plots by vegetation community AQR by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	1	6	FLI	1	6	EoF	0	0	FUR	1	6	BLSE	4	22	
TSE	7	39	FRE	2	11	Banks	1	6	EAST	2	11	HS_Lag	2	11	
TSR	3	17	BRU	8	44	upperEAST	0	0	SE	8	44	LMTR	0	0	
TWE	0	0	DAV	0	0	lowerEAST	0	0	SOUTH	0	0	LOMR	0	0	
KIN	7	39	FRA	0	0	SE	2	11	WEST	0	0	Mar_In	7	39	
TNS	0	0	OTW	4	22	SEinshore	8	44	KING	4	22	MTDRV	2	11	
			BGS	3	17	SW	0	0	NWEST	3	17	Open	3	17	
						WEST	0	0	eastNORTH	0	0				
						NWEST	7	39							
						NORTH	0	0							
	18	100		18	100		18	100		18	100		18	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 18 plots), 6% of the plots are in region FLI, **11% in region FRE**, **44% in region BRU**, 0% in region DAV, 0% in region FRA, **22% in region OTW**, and **17% in region BGS**.

AQR is a somewhat restricted vegetation community, unfortunately only 18 plots were surveyed in this study. This community was absent in several regions of all regionalisation types (IBRA – TWE, TNS, IMCRA – DAV, FRA, Estuarine – LMTR, LOMR), while BOM coast recorded AQR in only four (Banks, SE, SEinshore, NWEST) of the 10 districts. Primary dominance (≥30%) was high, especially in IBRA (TSE, KING, 39%), IMCRA (BRU, 44%), BOM coast (SEinshore, 44%, NWEST, 39%), Geographic (SE, 44%) and Estuarine (Mar_In, 39%). Secondary dominance (20-29%) was observed in only three regions IMCRA (OTW), Geographic (KING) and Estuarine (BLSE), all recoding 22%. Tertiary dominance (10-19%) was present in all regions ranging from 11 to 17%, however, care must be taken in this case as actual plot numbers (2 and 3) are very low. Generally, this community is dissimilar to previously discussed communities as it is restricted to Tasmania's southeast (IBRA, TSE, 39%, BOM coast, SEinshore, 44%) and the far northwest area (IBRA, KIN, 39%, BOM coast, NWEST, 39%). Interestingly, this vegetation favours the Estuarine classification Mar_In, which is also the most prominent setting for the previous vegetation

communities in this classification. The analysis does come with a caveat, this was a very small sample (n = 18) and seemingly very restricted in its position in the landscape. Further field work may uncover new instances of the community in differing regions.

Vegetation community ARH (rushes and herbs)

Table 3.37: Number and percentage (%) of plots by vegetation community ARH by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	9	16	FLI	2	4	EoF	4	7	FUR	2	4	BLSE	14	25	
TSE	16	28	FRE	8	14	Banks	0	0	EAST	8	14	HS_Lag	6	11	
TSR	16	28	BRU	25	44	upperEAST	3	5	SE	26	46	LMTR	3	5	
TWE	8	14	DAV	7	12	lowerEAST	3	5	SOUTH	6	11	LOMR	3	5	
KIN	8	14	FRA	7	12	SE	6	11	WEST	7	12	Mar_In	10	18	
TNS	0	0	OTW	3	5	SEinshore	23	40	KING	3	5	MTDRV	11	19	
			BGS	5	9	SW	3	5	NWEST	3	5	Open	10	18	
						WEST	5	9	eastNORTH	2	4				
						NWEST	7	12							
						NORTH	3	5							
	57	100		57	100		57	100		57	100		57	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 57 plots), 4% of the plots are in region FLI, **14% in region FRE**, **44% in region BRU**, **12% in region DAV**, **12% in region FRA**, 5% in region OTW, and 9% in region BGS.

Vegetation community ARH was found in each region of IMCRA, Geographic and Estuarine, although displayed low presence in some regions (e.g. Geographic, eastNORTH, 4%). It was absent in IBRA (TNS) and BOM coast (Banks). High levels of primary dominance were observed in IMCRA (BRU, 44%) and Geographic (SE, 46%), with primary dominance (≥30%) also recorded in BOM coast (SEinshore, 40%). IBRA (TSE and TSR, both 28%) and Estuarine (BLSE, 25%) displayed secondary dominance (20-29%), while many regions (e.g. IBRA, FUR, 16%; BOM coast, NWEST, 12%) recorded tertiary dominance (10-19%). The vegetation community appears widespread (>10%) in several regionalisations, IBRA (5 from six regions), Estuarine (5 from seven classes), IMCRA (4 from seven regions) and Geographic (4 from eight regions). However, presence in BOM coast is restricted to three of the 10

districts, which implies that two key envelopes of community ARH, one in SEinshore/SE (contiguous regions) and NWEST exist in the State. This suggests that the two BOM coast regions could be reasonable indicators of the presence of ARH.

Vegetation community ASH (shrubs and herbs)

Table 3.38: Number and percentage (%) of plots by vegetation community ASH by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	13	27	FLI	2	4	EoF	0	0	FUR	2	4	BLSE	3	6	
TSE	29	59	FRE	16	33	Banks	5	10	EAST	18	37	HS_Lag	2	4	
TSR	2	4	BRU	20	41	upperEAST	5	10	SE	18	37	LMTR	0	0	
TWE	0	0	DAV	0	0	lowerEAST	15	31	SOUTH	0	0	LOMR	0	0	
KIN	5	10	FRA	0	0	SE	0	0	WEST	0	0	Mar_In	37	76	
TNS	0	0	OTW	3	6	SEinshore	16	33	KING	3	6	MTDRV	4	8	
			BGS	8	16	SW	0	0	NWEST	3	6	Open	3	6	
						WEST	0	0	eastNORTH	5	10				
						NWEST	5	10							
						NORTH	3	6							
	49	100		49	100		49	100		49	100		49	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 49 plots), 4% of the plots are in region FLI, **33% in region FRE**, **41% in region BRU**, 0% in region DAV, 0% in region FRA, 6% in region OTW, and **16% in region BGS**.

No regionalisation recorded community ASH in every region, in fact ASH was absent from two or more regions in each regionalisation, and when very low incidence was taken into consideration, ASH was restricted to just two regions in each regionalisation, and further restricted to one in Estuarine classification. High primary dominance was found in Estuarine (Mar_In, 76%), IBRA (TSE, 59%) and IMCRA (BRU, 41%). Other levels of primary dominance (≥30%) were recorded in BOM coast (SEinshore, 33% and lowerEAST, 31%) and Geographic (EAST and SE, both 37%). Just one observation of each of secondary and tertiary dominance were recorded in IBRA (FUR, 27%) and IMCRA (BGS, 16%). High levels of primary dominance of community ASH in a limited selection of regions from all regionalisations, strongly indicates the prevalence of ASH to the east-lower east coast of the State and noticeably favouring

marine inlets. This does not suggest that ASH has not been recorded in other regions (or other Estuarine classes), it has, however, a very limited extent.

Vegetation community ASQ (Sarcocornia quinqueflora)

Table 3.39: Number and percentage (%) of plots by vegetation community ASQ by regionalisation type. Values (number of plots and percentage) in **blue** display primary dominance (≥30%), those in **red** show secondary dominance (20-29%), while those in **green** display tertiary dominance (10-19%, generally <10% excluded) within each individual regionalisation. Region order begins at Flinders/Furneaux and continues in a clockwise fashion. **For region codes see Table 3.31.**

Focus of table is region and regionalisation regions, therefore data is viewed by column.

Regionalisation															
IBRA			IMCRA			BOM coast			Geographic			Estuarine			
Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	Region	Plot	%	
FUR	15	18	FLI	0	0	EoF	0	0	FUR	0	0	BLSE	4	5	
TSE	53	62	FRE	32	38	Banks	5	6	EAST	35	41	HS_Lag	15	18	
TSR	5	6	BRU	32	38	upperEAST	7	8	SE	29	34	LMTR	5	6	
TWE	2	2	DAV	0	0	lowerEAST	27	32	SOUTH	0	0	LOMR	0	0	
KIN	10	12	FRA	4	5	SE	0	0	WEST	4	5	Mar_In	45	53	
TNS	0	0	OTW	1	1	SEinshore	28	33	KING	1	1	MTDRV	7	8	
			BGS	16	18	SW	0	0	NWEST	8	9	Open	9	11	
						WEST	2	2	eastNORTH	8	9				
						NWEST	9	11							
						NORTH	7	8							
	85	100		85	100		85	100		85	100		85	100	

Note: the percent column value is the percentage of plots within each region by individual regionalisation, viewed by column. For example, **IMCRA** (total 85 plots), 3% of the plots are in region FLI, **38% in region FRE**, **38% in region BRU**, 0% in region DAV, 5% in region FRA, 1% in region OTW, and **18% in region BGS**.

Again, another vegetation community that has a strong presence within east coast regions. ASQ was found in each regionalisation, missing in very few regions (e.g. TNS in IBRA, DAV in IMCRA, SOUTH and FUR in Geographic). Very high primary dominance was observed in IBRA region TSE (62%), Geographic region EAST (41%), and Estuarine class Mar_In (53%). Primary dominance (≥30%) was also recorded in IMCRA regions FRE and BRU (both 38%), BOM coast districts SEinshore and lowerEAST (33 and 32% respectively) and Geographic region SE (34%). All region pairs (e.g. IMCRA regions FRE and BRU) are contiguous and located on the State's east coast. Tertiary dominance (10-19%) was observed in IBRA regions FUR and KING (18 and 12%), IMCRA region BGS (18%), BOM coast district (NWEST (11%) and Estuarine classes (HS-Lag and Open (18 and 11% respectively). In all cases, tertiary dominance existed in regions based on King and Flinders islands; Estuarine class

hypersaline lagoons (HS_Lag) are present on Flinders Island and the far northeast of Tasmania. No levels of secondary dominance were observed, possibly due to the high incidences of primary dominance.

Summary

Most vegetation communities showed a preference for Tasmanian east coast-based regions, irrespective of regionalisation type. Communities AGH, AHM, AHR, ARH, ASH and ASQ favoured those regions located in the east/lower east; community AJK preferred the lower southeast, south and west, with presence on the far northwest, while AQR appeared the most restrictive of all vegetation communities with presence confined to south east and far northwest. In respect to Estuarine classes, marine inlets were the most favoured location for most vegetation communities (AGH, AHM, AHR, AQR, ASH and ASQ), with open locations preferred by AJK and barred, low-salinity estuaries favoured by ARH. However, the above comments are constrained by a caveat. Many Tasmania's coastal saltmarshes are concentrated on the State's east and southeast coasts, in marine inlets that provide maximum protection from destructive and erosive elements, principally onshore winds and high seas.

3.4.14 Indicator vegetation communities by individual region

Each coastal regionalisation type was analysed for indicator vegetation communities.

IBRA

Of the eight vegetation communities, two (25%) were identified as indicator communities ($p<0.05$) for the six regions (Table 3.40). The table includes all communities to $p<0.1$ which provides a useful interpretation of community fit within each region.

Table 3.40: Indicator vegetation communities (p<0.1) for each IBRA region (region order is clockwise from northeast Tasmania, commencing at Flinders Island). **Component A** = *positive predictive value;* **Component B** = *sensitivity* – see section 3.3.5. **Note**: vegetation communities are ordered by p-value then by "Stat" within each region. Those communities at p<0.05 are highlighted.

IBRA region codes: FUR = Flinders (FUR02), TSE = Tasmanian South East, TSR = Tasmanian Southern Ranges, TWE = Tasmanian West, KIN = King, TNS = Tasmanian Northern Slopes.

Region	Vegetation community	A	B	IndVal	Stat	p-value	
FUR	ASQ	0.9224	0.2382	0.2197	0.469	0.070	.
TSE	ASQ	0.9224	0.2382	0.2197	0.469	0.070	.
TSR	ARH	0.7860	0.2391	0.1879	0.434	0.030	*
	AHR	0.7481	0.1630	0.1219	0.349	0.070	.
TWE	ARH	0.7860	0.2391	0.1879	0.434	0.030	*
	AHR	0.7481	0.1630	0.1219	0.349	0.070	.
	ASQ	0.9224	0.2382	0.2197	0.469	0.070	.
KIN	ARH	0.7860	0.2391	0.1879	0.434	0.030	*
	ASQ	0.9224	0.2382	0.2197	0.469	0.070	.
TNS	AJK	0.5319	0.6000	0.3191	0.565	0.006	**
	AHR	0.7481	0.1630	0.1219	0.349	0.070	.

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Section 3.3.5).

The two vegetation communities identified as significant region indicators were AJK (p=0.006) and ARH (p=0.030), where AJK represented the TNS region, and ARH the TSR, TWE and KIN regions. Two other communities, AHR and ASQ (both p=0.070), although less significant, could be useful in combination with AJK and ARH in determining IBRA regions. This scenario would not be entirely satisfactory as ARH and AHR were identified to three regions, while, ASQ was identified to four regions. However, this does not diminish the usefulness of community AJK being an identifier for region TNS.

IMCRA

Of the eight vegetation communities, four communities (50%) were identified as indicator communities (p<0.05) for the seven regions (Table 3.41). The table includes all communities to p<0.1, thus providing a valuable understanding of vegetation community fit within each region. Each IMCRA region had a combination of two or more vegetation communities which act as indicators for that region.

Table 3.41: Indicator vegetation communities (p<0.1) for each IMCRA region (region order is clockwise from northeast Tasmania, commencing at Flinders Island). **Component A** = *positive predictive value;* **Component B** = *sensitivity* – see section 3.3.5. **Note**: vegetation communities are ordered p-value, then "Stat" within each region. Those communities at p<0.05 are highlighted.

Region codes: FLI = Flinders, FRE = Freycinet, BRU = Bruny, DAV = Davey, FRA = Franklin, OTW = Otway, BGS = Boags.

Region	Vegetation community	A	B	IndVal	Stat	p-value	
FLI	AQR	0.7741	0.2174	0.1683	0.410	0.005	**
	ARH	0.7806	0.2754	0.2150	0.464	0.011	*
	AHM	1.0000	0.1676	0.1676	0.409	0.092	.
FRE	ASQ	1.0000	0.2231	0.2231	0.472	0.032	*
	AHM	1.0000	0.1676	0.1676	0.409	0.092	.
BRU	ASQ	1.0000	0.2231	0.2231	0.472	0.032	*
	AHM	1.0000	0.1676	0.1676	0.409	0.092	.
DAV	AJK	0.6074	0.5294	0.3216	0.567	0.001	***
	ARH	0.7806	0.2754	0.2150	0.464	0.011	*
FRA	ARH	0.7806	0.2754	0.2150	0.464	0.011	*
	ASQ	1.0000	0.2231	0.2231	0.472	0.032	*
	AHM	1.0000	0.1676	0.1676	0.409	0.092	.
OTW	AQR	0.7741	0.2174	0.1683	0.410	0.005	**
	ARH	0.7806	0.2754	0.2150	0.464	0.011	*
	ASQ	1.0000	0.2231	0.2231	0.472	0.032	*
BGS	ASQ	1.0000	0.2231	0.2231	0.472	0.032	*
	AHM	1.0000	0.1676	0.1676	0.409	0.092	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Section 3.3.5).

The four vegetation communities identified as significant region indicators were AJK (p=0.001), AQR (p=0.005), ARH (p=0.011) and ASQ (p=0.032), with AJK representing the DAV region, AQR the FLI and OTW regions, ARH the FLI, DAV and FRA regions and ASQ the FRE, BRU, FRA, OTW and BGS regions (Table 3.41). One other community, AHM (p=0.092), although less significant, could be useful in combination with the communities, except for AJK, in determining IMCRA regions. This scenario does provide a degree of usefulness as four vegetation communities, either individually or in combination, are helpful to define regions, although at a broader scale. Three regions, BGS, FRE and BRU, each have ASQ (p=0.032) and AHM (p=0.092), all adjoin, and represent the north and east coasts of Tasmania. The combination of ASQ and AHM does not confirm which IMCRA region is which (either BGS, FRE or BRU), however, a degree of assurance is provided as to which community (ASQ/AHM) should be realised in that area. Communities AJK and ARH, in combination, do verify the DAV region, as do ARH, ASQ and AHM in

combination, confirm region FRA. Interestingly, both FLI (comprising the Furneaux Island only) and OTW (comprising King and Fleurieu Islands and the extreme far northwest) are both represented by AQR (p=0.005) and ARH (p=0.011) in combination, however, the third vegetation community differs. In the instance of FLI, community AHM (p=0.092) is included, while for OTW, community ASQ (p=0.032) makes up indicator group.

BOM coastal

Herein "district" and "region" are interchangeable and used depending on the context within the text.

Of the eight vegetation communities, just one community (12.5%) was identified as an indicator community (p<0.05) for the seven districts (Table 3.42). The table also includes communities to p<0.1 presenting a better interpretation of community fit within each region.

Table 3.42: Indicator plant species (p<0.1) for each BOM coastal district (district order is clockwise from northeast Tasmania, commencing at Flinders Island). **Component A** = *positive predictive value;* **Component B** = *sensitivity* – see section 3.3.5. **Note**: vegetation communities are ordered p-value, then "Stat" within each district. Those communities at p<0.05 are highlighted.

District codes: EoF = East of Flinders Island, Banks = Banks Strait, upperEAST = Upper East Coast, lowerEAST = Lower East Coast, SE = Southeast Coast, SEinshore = Southeast Inshore, SW = Southwest Coast, WEST = Central West Coast, NWEST = Far Northwest Coast, NORTH = Central North Coast.

District	Vegetation community	A	B	IndVal	Stat	p-value	
EoF	AHM	0.8672	0.2098	0.1819	0.426	0.099	.
Banks	AHM	0.8672	0.2098	0.1819	0.426	0.099	.
upperEAST	AHM	0.8672	0.2098	0.1819	0.426	0.099	.
lowerEAST	AHM	0.8672	0.2098	0.1819	0.426	0.099	.
SE	ARH	0.5797	0.8182	0.4743	0.689	0.001	***
SEinshore	*NO VEGETATION COMMUNITY IDENTIFIED*						
SW	ARH	0.5797	0.8182	0.4743	0.689	0.001	***
WEST	AHM	0.8672	0.2098	0.1819	0.426	0.099	.
NWEST	*NO VEGETATION COMMUNITY IDENTIFIED*						
NORTH	AHM	0.8672	0.2098	0.1819	0.426	0.099	.

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Section 3.3.5).

Vegetation community ARH (p=0.001) is the only one that recorded significance as an indicator community for BOM coastal districts, in this instance, districts SE and SW. Community AHM (p=0.099) was identified as suitable for districts EoF, Banks, upperEAST, lowerEAST, WEST and NORTH, with two districts, SEinshore and

NWEST, recording no vegetation community as an identifier. BOM coastal districts is a poor example of vegetation communities being district identifiers as there was only one community that displayed significance, this over two districts, six districts were identified by the same community (AHM), this at "low significance" (p=0.099), and no community identifier for the remaining two districts.

Geographic regions

Of the eight vegetation communities, only two communities (25%) were identified as indicator communities (p<0.05) for the eight regions classes (Table 3.43). The table includes all communities to p<0.1 providing a complete interpretation of community fit within each region.

Table 3.43: Indicator vegetation communities (p<0.01) for each Geographic region (region order is clockwise from northeast Tasmania, commencing at Flinders Island). **Component A** = *positive predictive value;* **Component B** = *sensitivity* – see section 3.3.5. **Note**: vegetation communities are ordered p-value, then "Stat" within each region. Those communities at p<0.05 are highlighted.

Geographic region codes: FUR = Furneaux, EAST = East, SE = Southeast, SOUTH = South, WEST = West, KING = King, NWEST = Northwest, eastNORTH = East North. Terminology follows Edgar (1999).

Region	Vegetation community	A	B	IndVal	Stat	p-value	
FUR	AQR	0.7298	0.2174	0.1587	0.398	0.024	*
	AHM	0.8969	0.1991	0.1786	0.423	0.097	.
EAST	AHM	0.8969	0.1991	0.1786	0.423	0.097	.
SE	*NO VEGETATION COMMUNITY IDENTIFIED*						
SOUTH	ARH	0.4459	0.8751	0.3902	0.618	0.001	***
WEST	AHM	0.8969	0.1991	0.1786	0.423	0.097	.
KING	AQR	0.7298	0.2174	0.1587	0.398	0.024	*
NWEST	AHM	0.8969	0.1991	0.1786	0.423	0.097	.
eastNORTH	AHM	0.8969	0.1991	0.1786	0.423	0.097	.

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Section 3.3.5).

The two vegetation communities identified as significant region indicators were ARH (p=0.001) and AQR (p=0.024), where ARH represented the SOUTH region, and AQR, the FUR and KING regions. One other community, AHM (p=0.097), although less significant, was recorded as an indicator for EAST, WEST, NWEST and eastNORTH Geographic regions. No vegetation community was found as an indicator for region SE. Similar to IBRA, this scenario would not be entirely satisfactory as three communities represented seven of the eight regions. It is interesting to note the similarity of vegetation community AQR in both IMCRA and Geographic regionalisations. In each case AQR was identified as the key indicator for the Flinders

area (IMCRA – FLI, Geographic – FUR) and the King area (IMCRA – OTW, Geographic – KING).

Estuarine

Herein "class" and "region" are interchangeable and used depending on the context within the text.

Of the eight vegetation communities, two communities (25%) were identified as indicator communities ($p<0.05$) for the seven classes (Table 3.44). No vegetation community was identified between $p<0.05$ and $p<0.1$ within this classification.

Table 3.44: Indicator vegetation communities ($p<0.05$) for each Estuarine class (class order alphabetical). **Component A** = *positive predictive value;* **Component B** = *sensitivity* – see section 3.3.5. **Note**: vegetation communities are ordered p-value, then "Stat" within each class.

Estuarine class codes: BLSE = barred, low salinity estuary, HS_Lag = hypersaline lagoon, LMTR = large meso-tidal river, LOMR = large, open micro-tidal river, Mar_In = marine inlet, MTDRV = micro-tidal drowned river valley, Open = open estuary. Terminology follows Edgar (1999).

Class	Vegetation community	A	B	IndVal	Stat	p-value	
BLSE	ARH	0.8779	0.2384	0.2093	0.457	0.012	*
HS_Lag	*NO VEGETATION COMMUNITY IDENTIFIED*						
LMTR	ARH	0.8779	0.2384	0.2093	0.457	0.012	*
	AJK	0.6710	0.2329	0.1563	0.395	0.018	*
LOMR	ARH	0.8779	0.2384	0.2093	0.457	0.012	*
Mar_In	*NO VEGETATION COMMUNITY IDENTIFIED*						
MTDRV	ARH	0.8779	0.2384	0.2093	0.457	0.012	*
Open	ARH	0.8779	0.2384	0.2093	0.457	0.012	*
	AJK	0.671	0.2329	0.1563	0.395	0.018	*

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Section 3.3.5).

The two vegetation communities identified as significant class indicators were ARH ($p=0.012$) and AJK ($p=0.018$), where ARH characterised BLSE, LOMR and MTDRV classes, and jointly with AJK, described LMTR and Open classes. No vegetation community was found as a descriptor for classes HS_Lag and Mar_In. Like IBRA and Geographic regionalisations, this scenario would not be suitable as two communities represented five of the seven regions, and no community was identified as an indicator for two regions.

It was interesting to note that vegetation community ARH had been identified as an indicator community for each regionalisation, BOM districts and Estuarine classification. ARH p-values ranged from 0.001 to 0.030.

The best fit

To determine which regionalisation was best represented by indicator vegetation communities, each regionalisation (Tables 3.40 to 3.44) was examined for specific differences in terms of numbers of vegetation communities and p-values that best describe each (Table 3.45).

Table 3.45: An analysis of best fit attributes for vegetation communities, based on individual regionalisation type. Regionalisation type order as per presented above.

No. as indicators = number of vegetation communities that act as indicators (at p<0.1) for regions (within individual regionalisation type); **p-value <0.001 etc** = number of vegetation communities that record p-value to individual p-value bracket; **Region with no identifier** = number of regions (within individual regionalisation type) that has no indicator at p<0.1.

		Vegetation communities					
Regionalisation type	**Regions**	**No. as indicators**	**p-value <0.001**	**p-value 0.001-0.01**	**p-value 0.01-0.05**	**p-value 0.05-0.10**	**Region with no identifier**
IBRA	6	3	0	1	1	1	0
IMCRA	7	5	1	1	2	1	0
BOM coastal	10	2	1	0	0	1	2
Geographic	8	3	1	0	1	1	1
Estuarine	7	2	0	0	2	0	2

Regionalisation types BOM coastal, Geographic and Estuarine can be discounted, as in each, at least one region could not be identified by a vegetation group (e.g. BOM coastal – SEinshore, NWEST; Estuarine – HS_Lag, Mar_In). Furthermore, in each case, one community represented more than four individual regions (e.g. BOM coastal – AHM was key indicator for six districts). This leaves IBRA and IMCRA in contention for regionalisation that best represents coastal saltmarsh vegetation patterning. IBRA has three different vegetation communities that represent six regions (50%), while IMCRA has five separate communities that represent seven regions (71%). IBRA has no community that is highly significant ($p<0.001$) and one in each of the remaining p-value brackets ($p<0.01$; $p<0.05$; $p<0.10$). IMCRA has one vegetation community that is highly significant, and one, two and one communities (respectively) in the remaining p-value brackets, therefore, IMCRA appears to harbour greater vegetation community diversity than does IBRA. However, neither regionalisation suggests distinctive vegetation patterning, as individual regions from both have shared single communities (e.g. IBRA regions FUR and TSE each exhibit ASQ), or shared combinations of communities (IMCRA regions FRE, BRU and BGS each depict ASQ/AHM). It is apparent that the unevenness of field-plot numbers by region (see Table 3.31) is

possibly one of the principal causes in failing to reach a definite conclusion where saltmarsh vegetation patterning is determined by regionalisation. Several regions, irrespective of regionalisation type, recorded low plot numbers (e.g. IBRA region TNS – 1%, region TWE – 6%; IMCRA region FLI – 2%, region OTW – 3%). Similarly, identical regions within different regionalisations exhibited differing plot numbers, for example far northeast coast including Furneaux group (IBRA region FUR – 17%; IMCRA region FLI – 2%) (see Table 3.30). This makes comparisons between regions and between regionalisations, less reliable. From a field-based perspective, and solely as a personal view, IMCRA does appear to be the better fit to document vegetation community presence. However, until further field assessments, particularly on the State's south and lower west coasts, can be completed in the future, it should be resolved that saltmarsh vegetation patterning does not appear to conform closely to any pre-existing regionalisation of the biophysical environment in Tasmania.

3.5 Conclusions

Tasmanian coastal saltmarsh vegetation communities display high diversity containing more than half of Australia's saltmarsh flora. Broad scale interpretation, that used by TASVEG from aerial imagery, is suitable for mapping purposes, however, as saltmarsh research has increased during the later years, an improved vegetation community classification system, at a finer scale, is required to standardise current and future saltmarsh studies to a consistent and uniform manner.

Using established and accepted methods for vegetation assessment and hierarchical classification, eight coastal saltmarsh vegetation communities have been identified on a Tasmanian state-wide basis. Floristic classification by Kirkpatrick and Glasby (1981) based on their study area in south eastern Tasmanian, and then applied Tasmanian state-wide (at seven community groups), matches well with the results from this study (at eight community groups). The classification proposed by Bridgewater and Cresswell (2003) has missed several key species, perhaps due to the use of an earlier version of the Australian Virtual Herbarium, which has been updated a number of times since 2003.

This study has found that the current saltmarsh TASVEG vegetation community classifications, ASS and ARS, though useful at a broad scale, especially when interpreting aerial photography, do not properly reflect the plant species diversity and

association between individual species when viewing the same at ground level. There are often cross associations between individual species found within TASVEG's ASS and ARS classes which, when viewed at ground level/finer scale, tend to individualise vegetation communities. The plant species *J. kraussii* is a good example. From aerial images, this species is classed as ARS. However, on closer examination, *J. kraussii* is found as an individual community, can form a community where, with a cover value greater than 50% and associated with succulent herbs, such as *S. repens* and *S. quinqueflora* (community ARH), and form another community type where cover value is less than 50% and is associated with succulent herbs, such as, *S. repens* and *D. crassifolium* (vegetation community AHR). In another example, *T. arbuscula* (botanically classed as a succulent), is a shrub which grows to 2 metres, while *S. quinqueflora* is a succulent herb, which grows to approximately 0.3 metres, yet, though significantly structurally different, both are classified as ASS from aerial imagery.

From a research viewpoint, classifying coastal saltmarsh vegetation to the proposed finer scale, does distinguish structural form, species classes (whether herbs or graminoid) and species associations. With a finer scale classification, ecological studies will be able to attribute various aspects, such as edaphic factors (see Chapter 4), and terrestrial and benthic invertebrates' assemblages to individual vegetation communities and provide a better understanding of the ecological importance of coastal wetlands.

The proposed new typology is justified as it demonstrates the differences between species combinations and relationships, and each group's position in the coastal saltmarsh landscape, where climatic variables can, and do play, an identified role.

Aligning the newly defined vegetation communities to pre-existing natural regionalisations was somewhat troublesome with no tangible clear-cut result. Three potential regionalisations, BOM coastal, Geographic and Estuarine were declared misfits, as in several cases one community represented several regions, and in other instances, some regions exhibited no community indicator. IBRA regionalisation was rated at 50% with no highly significant indicator community, while IMCRA scored over 70% with one highly significant indicator, followed by others as significant. Nevertheless, neither regionalisation type implied unambiguous vegetation patterning, suggesting coastal saltmarsh does not fit to pre-existing regionalisations.

The original study aims have been met, in so much that there is an unacceptable variability in current TASVEG classifications at a fine scale, and these classifications as they stand, are unsuitable for a consistent approach in saltmarsh study, monitoring and restoration. It is noted that saltmarsh vegetation community delineation and classification is a somewhat difficult task when using aerial photography. While this identification is still very useful at a broad scale, these results should be viewed as an indication to vegetation community type to be expected in the field. However, prior to any saltmarsh studies, any individual site should be "ground-truthed" to determine the true onsite vegetation community type and then its suitability as a study site.

Now armed with adequate resources – a vegetation community identification key, a hierarchical classification and new typology – field workers can, with confidence, identify coastal saltmarsh vegetation communities and record field information aligned to that community, which will in turn standardise and improve ecological and conservation research in this severely threatened coastal environment.

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3.8 Appendices

3A.1 Study sites and weather observation stations.

3A.2 SSE plots from k-means clustering

3A.1 Study sites and weather observation stations.

Table 3A.1: Training, Test 1 and Test 2 study sites, weather observation stations with BOM reference numbers, and availability of rainfall, temperature and solar exposure records in years, and associated sites. **Source:** BOM (2017).

			Type of weather records		
Study sites	**Weather observation station**	**BOM ref No.**	**Rainfall**	**Temp**	**Solar exposure**
1. (Flinders) Long Point	Flinders Island Airport	99005	✓	✓	✓
2. Musselroe Bay	Rushy Lagoon Eddystone Point	92067 92045	✓	 ✓	✓
3. Henderson Lagoon	Falmouth (Glencoe) St Helens Aerodrome	92076 92120	✓	 ✓	✓
4. Long Point	Swansea Post Office	92038	✓	✓	✓
5. Chinamans Bay	Point Lesueur	92124	✓	✓	✓
6. Dorans Road	Hobart Airport	94008	✓	✓	✓
7. South Arm	Fort Dennison Bull Bay	94022 94166	✓	 ✓	✓
8. Port Cygnet	Cygnet Geeveston	94219 94137	✓	 ✓	✓
9. Lutregala Marsh	Alonnah Dennes Point	94070 94255	✓	 ✓	✓
10. Castle Forbes Bay	Geeveston	94137	✓	✓	✓
11. Esperance River	Dover	94020	✓	✓	✓
12. Hastings Bay	Southport Dover	94192 94020	✓	 ✓	✓
13. Ida Bay	Southport Dover	94192 94020	✓	 ✓	✓
14. Lowana Point	Strahan Aerodrome	97072	✓	✓	✓
15. Cat Island	Strahan Aerodrome	97072	✓	✓	✓
16. Mill Bay	Strahan Aerodrome	97072	✓	✓	✓
17. Sea Elephant Bay	Naracoopa King Island Airport	98004 98017	✓	 ✓	✓
18. West Inlet	Smithton Aerodrome	91292	✓	✓	✓
19. Snake Creek	Smithton Aerodrome	91292	✓	✓	✓
20. Singletons Point	Ulverstone Burnie (Round Hill)	91102 91009	✓	 ✓	✓
21. Forth River	Forthside Devonport Airport	91186 91126	✓	 ✓	✓
22. Sams Spit	St Helens Aerodrome	92120	✓	✓	✓

Study sites	Weather observation station	BOM ref No.	Type of weather records		
			Rainfall	Temp	Solar exposure
23. Georges Bay	St Helens Aerodrome	92120	✓	✓	✓
24. Scamander River	Upper Scamander St Helens Aerodrome	92130 92120	✓	✓	✓
25. Long Point	Swansea Post Office	92038	✓	✓	✓
26. Snug	Margate Dennes Point	94125 94255	✓	✓	✓
27. Margate	Margate Dennes Point	94125 94255	✓	✓	✓
28. Pelican Point	St Helens Aerodrome	92120	✓	✓	✓
29. Lords Point	St Helens Aerodrome	92120	✓	✓	✓
30. Sedbury Ck	Bream Creek Dunalley	92005 94254	✓	✓	✓
31. Carlton River	Dodges Ferry Hobart Airport	94221 94008	✓	✓	✓
32. Bresnehans Ck	Triabunna Orford	92127 92077	✓	✓	✓
33. Clarence Plains R	Mt Rumney Hobart Airport	94082 94008	✓	✓	✓
34. Hildyards Pt	Bream Creek Dunalley	92005 94254	✓	✓	✓
35. Watch House Bay	Little Swanport Swansea Post Office	92112 92038	✓	✓	✓
36. Saltwater Ck	Bull Bay Dennes Point	94166 94255	✓	✓	✓
37. Earlham Lagoon	Orford Orford	92028 92027	✓	✓	✓
38. Burdons Marsh	Koonya Heights Premaydena Hatchery Dunalley	94240 94053 94254	✓	✓	✓
39. Kermandie River	Geeveston	94137	✓	✓	✓
40. Old Beach	Bridgewater Hobart	94005 94029	✓	✓	✓
41. Railway Point	Hobart Airport	94008	✓	✓	✓
42. Cameron Inlet	Flinders Is Airport	99005	✓	✓	✓
43. Acton Bay	Montagu Smithton Aerodrome	91128 91292	✓	✓	✓
44. 4 Mile Ck	Point Lesueur	92124	✓	✓	✓
45. Pipers River	Low Head	91293	✓	✓	✓
46. Bakers Beach	Narawntapu Devonport Airport	91349 91126	✓	✓	✓
47. Detention River	Wynyard Airport	91107	✓	✓	✓
48. Bungaree Point	King Island Airport	98017	✓	✓	✓

Study sites	Weather observation station	BOM ref No.	Type of weather records		
			Rainfall	Temp	Solar exposure
49. Sloping Main	Koonya Heights Premaydena Hatchery Dunalley	94240 94053 94254	✓	✓	✓
50. Saltwater River	Koonya Heights Premaydena Hatchery Dunalley	94240 94053 94254	✓	✓	✓
51. Newmans Creek	Taranna Dunalley	94169 94254	✓	✓	✓
52. Moulting Lagoon 1	Apslawn Friendly Beaches	92001 92114	✓	✓	✓
53. Moulting Lagoon 2	Apslawn Friendly Beaches	92001 92114	✓	✓	✓
54. Luttrells Bay	Little Swanport Swansea Post Office	92112 92038	✓	✓	✓
55. Sheepwash Bay	Little Swanport Swansea Post Office	92112 92038	✓	✓	✓
56.Orielton Lagoon	Hobart Airport	94008	✓	✓	✓
57. Cockle Creek	Southport Dover	94192 94020	✓	✓	✓
58. Adventure Bay	Adventure Bay Cape Bruny Lighthouse	94159 94010	✓	✓	✓
59. Cloudy Bay	Cape Bruny Lighthouse	94010	✓	✓	✓
60. Cloudy Bay	Cape Bruny Lighthouse	94010	✓	✓	✓
61. Kingfisher Beach	Cape Bruny Lighthouse	94010	✓	✓	✓
62. Great Bay	Bull Bay Dennes Point	94166 94255	✓	✓	✓
63. Okehampton Beach Lagoon	Triabunna Orford	92127 92027	✓	✓	✓
64. Double Creek	Triabunna Orford	92127 92027	✓	✓	✓
65. Ringarooma River	Tomahawk Bridport	92127 91284	✓	✓	✓
66. Little Forester River	Bridport	91284	✓	✓	✓
67. Little Musselroe Bay 1	Rushy Lagoon Swan Island	92067 92045	✓	✓	✓
68. Little Musselroe Bay 2	Rushy Lagoon Swan Island	92067 92045	✓	✓	✓
69. Ansons Bay	Ansons Bay Larapuna	92129 92045	✓	✓	✓
70. Shark Bay	Ansons Bay Larapuna	92129 92045	✓	✓	✓
71. 5 Mile Beach	Hobart Airport	94008	✓	✓	✓
72. Surges Bay	Geeveston	94137	✓	✓	✓

Study sites	Weather observation station	BOM ref No.	Type of weather records		
			Rainfall	Temp	Solar exposure
73. Port Cygnet 2	Cygnet Geeveston	94219 94137	✓	✓	✓
74. Lisdillon	Lisdillon Farm	92021	✓	✓	✓
75. King George Sound	Bangor Hobart Airport	94149 94008	✓	✓	✓
76. Calverts Lagoon	Clifton Beach Dennes Point	94161 94255	✓	✓	✓
77. Prosser River	Orford Orford	92028 92027	✓	✓	✓
78. Cockle Bay Lagoon 1	Orford Orford	92028 92027	✓	✓	✓
79. Cockle Bay Lagoon 2	Orford Orford	92028 92027	✓	✓	✓
80. Blackman Bay Rivulet	Bangor Hobart Airport	94149 94008	✓	✓	✓
81. Swan Lagoon	Bangor Hobart Airport	94149 94008	✓	✓	✓
82. Granville Harbour	Granville Harbour Strahan	97036 97020	✓	✓	✓
83. Pieman River	Granville Harbour Strahan	97036 97020	✓	✓	✓
84. Arthur River	Marrawah	91223	✓	✓	✓
85. Couta Rocks	Marrawah	91223	✓	✓	✓
86. Nelson Bay	Marrawah	91223	✓	✓	✓
87. Bluff Hill Point	Marrawah	91223	✓	✓	✓
88. Robbins Passage 1	Montagu Smithton Aerodrome	91128 91292	✓	✓	✓
89. Robbins Passage 2	Montagu Smithton Aerodrome	91128 91292	✓	✓	✓
90. Davey River	Port Davey Maatsuyker Island	97007 94041	✓	✓	✓
91. James Kelly Basin	Port Davey Maatsuyker Island	97007 94041	✓	✓	✓

3A.2 SSE plots from k-means clustering

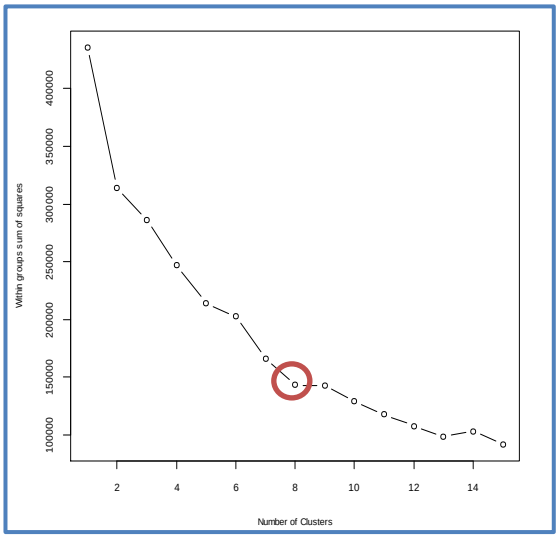

Figure 3A.2a: Plot SSE against sequential cluster levels – run 1 – "elbow" at 5(?) and 8 clusters.

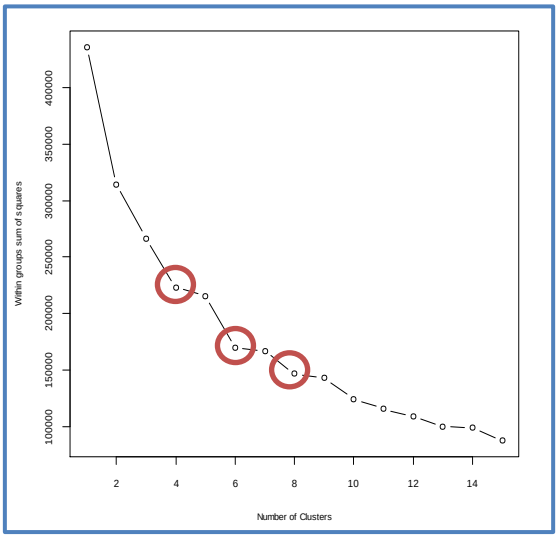

Figure 3A.2b: Plot SSE against sequential cluster levels – run 2 – "elbow" at 4, 6 and 8 clusters.

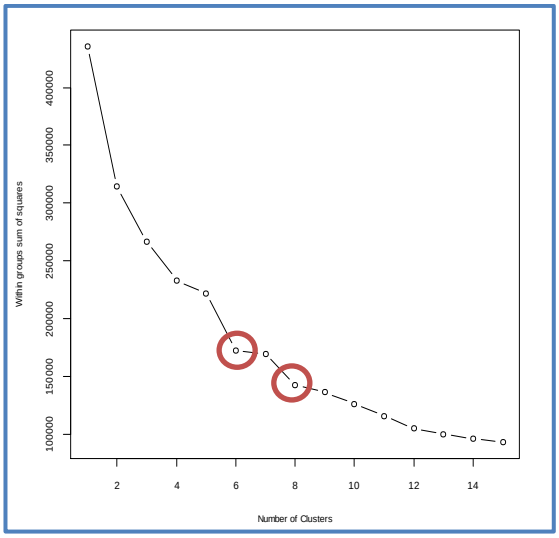

Figure 3A.2c: Plot SSE against sequential cluster levels – run 3 – "elbow" at 4(?), 6 and 8 clusters.

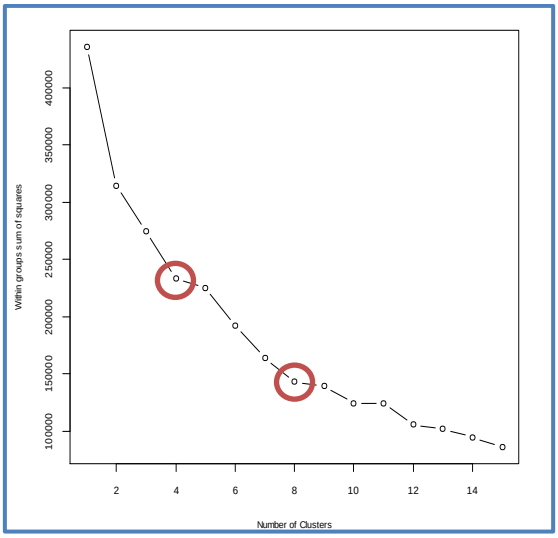

Figure 3A.2d: Plot SSE against sequential cluster levels – run 4 – "elbow" at 4 and 8 clusters.

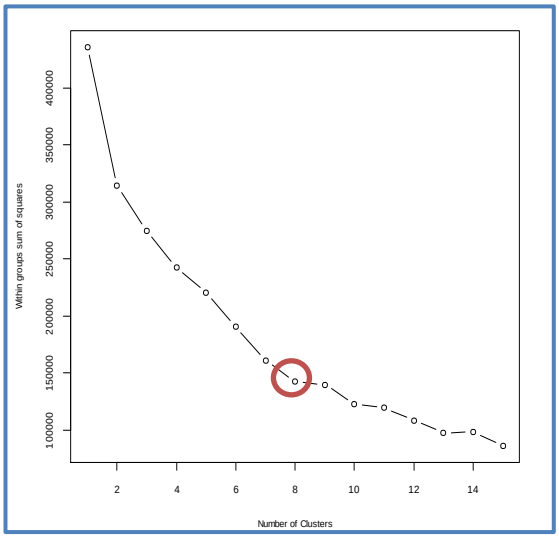

Figure 3A.2e: Plot SSE against sequential cluster levels – run 5 – "elbow" at 8 clusters.

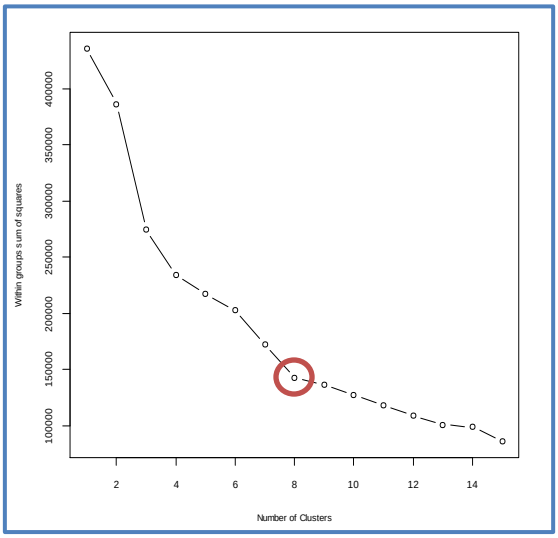

Figure 3A.2f: Plot SSE against sequential cluster levels – run 6 – "elbow" at 4(?) and 8 clusters.

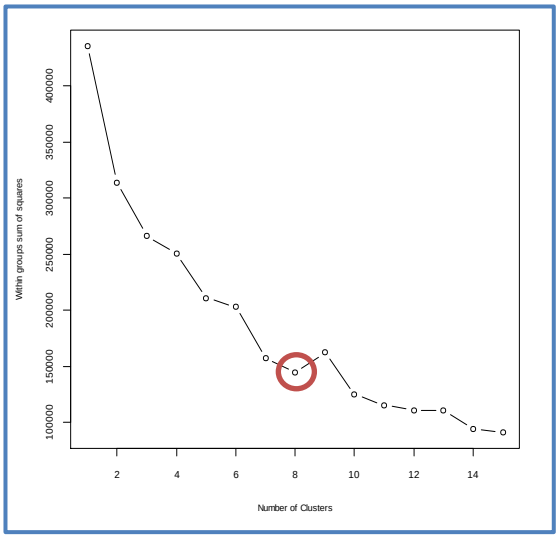

Figure 3A.2g: Plot SSE against sequential cluster levels – run 7 – "elbow" at 3(?), 5(?) and 8 clusters

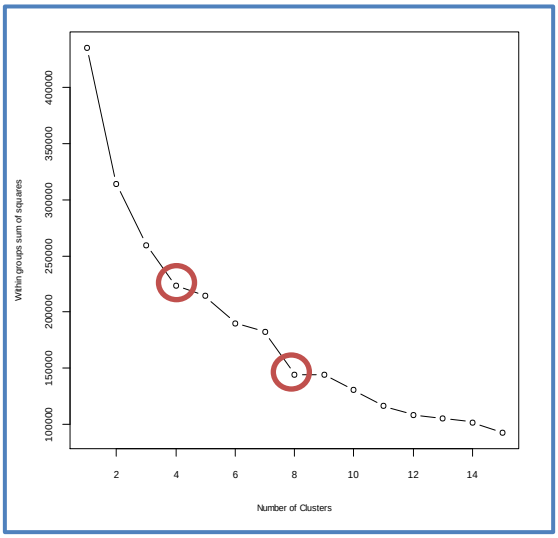

Figure 3A.2h: Plot SSE against sequential cluster levels – run 8 – "elbow" at 4 and 8 clusters

Chapter 4

Soils of Tasmanian coastal saltmarshes

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Chapter 4: Soils of Tasmanian coastal saltmarshes

4.1 Introduction

Saltmarsh soils are made up from sediments transported by fluvial flows, which are deposited on low-lying marine zones when flows decrease in velocity (Phleger 1977). These deposits are generally fine silts and clays that allow vascular plants to become established (Long & Mason 1983), and as vegetation increases in abundance, more sediment becomes trapped and the surrounding surface rises in elevation (Phleger 1977; Long & Mason 1983). Decaying plants contribute organic matter to the sediments, thereby increasing the nutrient supply to the established vegetation and stimulating further plant growth and regrowth. Biological activity breaks down the decaying plant matter and bioturbation by invertebrate burrowers transports detritus deeper into the sediment (Ranwell 1972) further improving and enriching the soil. Soil characteristics vary across saltmarsh zones and are dependent on the regularity of saltwater incursion, topography, erosion and vegetation type, in conjunction with environmental features such as wind, precipitation and evapotranspiration (Phleger 1977; Long & Mason 1983). Elemental soil characteristics include organic matter, salinity and pH (Montgomery *et al.* 2001), but other significant characteristics include moisture (Lowery *et al.* 1996), soil organic carbon, total carbon, (Doran & Parkin 1996; Sarrantonio *et al.* 1996), and bulk density (Blake 1965).

Moisture, and invariably salinity, varies considerably across a coastal saltmarsh gradient (Álvarez-Rogel *et al.* 2000; Silvestri *et al.* 2005; Aalders 2014). Areas that are prone to increased frequencies of tidal inundation have increased levels of moisture, whereas, those areas less frequently inundated have reduced levels of moisture (Long & Mason 1983). Studies in Tasmanian coastal saltmarshes by Richardson and Mulcahy (1996), Gouldthorpe (2000) and Aalders (2014) have repeatedly demonstrated increased moisture levels in the low marsh area, with decreasing levels progressing through the middle marsh to the upper marsh. As marine waters are saline, it would be expected that salinity would also decrease in levels from the low marsh to the upper marsh, as demonstrated by Adams (1963), Clarke and Hannon (1969) and Richardson and Mulcahy (1996). Variations in the levels of carbon and soil organic matter (SOM) have been reported in a similar manner to that of moisture and salinity, and in particular, a level of over 50% SOM in a vegetation community made up of the chenopods

Sarcocornia quinqueflora and *Tecticornia arbuscula* (Van Der Valk & Attiwill 1983), both plant species present in Tasmanian coastal saltmarshes.

The physical make-up of saltmarsh soils is largely a manifestation of sediment type, either marine or estuarine or a combination of both (Adam 1990). Clarke and Hannon (1967) found that the sand component ranged from 78% in the *Arthrocnemum* (now *Tecticornia*) zone to 69% in the *Juncus* zone (both genera also found in Tasmania), decreasing landward. However, it is difficult to quantify saltmarsh sand, silt and clay values on a universal basis, as the composition of adjacent landforms often determines the textural composition of saltmarsh soils (Long & Mason 1983; Adam 1990).

Recent studies have emphasised edaphic factors (soil related variables) such as salinity, tidal inundation and moisture as key drivers that determine zonation of vegetation communities and impact the survival of individual plant species (Snow & Vince 1984; Vince & Snow 1984; Partridge & Wilson 1989; Álvarez-Rogel *et al.* 2000; Huckle *et al.* 2000). Álvarez-Rogel *et al.* (2001) established that coastal vegetation can be used as a bioindicator of soil type, but this is challenged by Silvestri *et al.* (2005) who found that soil salinity was not a driver in the presence or absence of halophile plant species in saltmarshes. Many saltmarsh plant species have broadly overlapping salinity tolerances as is evident from the field (Clarke & Hannon 1970; Kirkpatrick & Glasby 1981; Engels & Jensen 2010; Landi & Angiolini 2015) and laboratory studies (Snow & Vince 1984; Baldwin & Mendelssohn 1998; Sharpe & Baldwin 2012).

4.1.1 International saltmarsh soil research

In recent years, with an increasing focus on conservation and restoration measures, a renewed and expanding interest in saltmarshes has evolved especially in Europe and North America (Desender *et al.* 1998; Desender & Maelfait 1999; Irmler *et al.* 2002; Finch *et al.* 2007; Pétillon *et al.* 2008). This has led to emerging studies into saltmarsh soils such as Snow and Vince (1984), Mendelssohn and McKee (1988), Álvarez-Rogel *et al.* (2001) and Pétillon *et al.* (2008). Increasingly, studies focus on the interactions between saltmarsh soils and individual plant species (Ungar 1998; Emery *et al.* 2001; Molina *et al.* 2003; Álvarez-Rogel *et al.* 2007; Engels & Jensen 2010; Day *et al.* 2013; Boaga *et al.* 2014; Landi & Angiolini 2015). In acknowledgement of the importance of carbon accumulation/sequestration in coastal saltmarshes, recent works have

highlighted soil carbon density values in various regions and latitudes with diverse dominant halophytic vegetation species (Ouyang & Lee 2014; Banerjee *et al.* 2017; Hansen *et al.* 2017; Mueller *et al.* 2017; Chew & Gallagher 2018; Himes-Cornell *et al.* 2018; Wollenberg *et al.* 2018). Furthermore, links have been established between climate variables (e.g. temperature, rainfall) and saltmarsh vegetation communities (Deil 2000; Fariña *et al.* 2018), therefore, it is worth exploring any connection between these variables and edaphic factors, and in turn vegetation communities.

4.1.2 Australian saltmarsh soil research

Research in Australia on saltmarsh soils had been somewhat limited. About 50 years ago, Clarke and Hannon (1967, 1969, 1970, 1971) explored the interactions between soils and plant species from the Sydney region. More recently, Van Der Valk and Attiwill (1983) completed a study on nutrients and litter decomposition, Clarke (1985) reported on nitrogen pools in the saltmarsh system, and Maher and Eyre (2010) completed a study of organic carbon in coastal estuarine bays of NSW coast. Lately, there has been an increasing focus on carbon storage and sequestration (termed "blue carbon") in Australian saltmarshes (Howe *et al.* 2009; Saintilan *et al.* 2013; Trevathan-Tackett *et al.* 2015; Kelleway *et al.* 2016; Kelleway *et al.* 2017; Macreadie *et al.* 2017; Lewis *et al.* 2018).

4.1.3 Tasmanian saltmarsh soil research

Tasmanian saltmarsh studies date back to 1947 (Curtis & Somerville 1947), however, mostly opportunistic studies on saltmarsh soils are evident from the 1980s (Kirkpatrick & Glasby 1981; Marsh 1982; Richardson *et al.* 1991; Richardson & Mulcahy 1996; Richardson *et al.* 1997, 1998). Ecological research into an estuarine burrowing crab *(Helograpsus haswellianus)* in the Derwent region (SE Tasmania) included edaphic factors such as soil moisture, organic matter and composition (Marsh 1982). Saltmarsh soils formed a major habitat component of an extensive state-wide study by Wong *et al.* (1993) on crustaceans and molluscs of Tasmanian saltmarshes. A thesis by Gouldthorpe (2000) researched the impacts of drainage and grazing on Derwent River marshes and reported on several soil factors. This was followed by a study into the impact of the invasive graminoid plant *Spartina anglica* (common cord grass, known in Australia as rice grass) in Little Swanport estuary (east coast Tasmania). Here environmental variables (e.g. salinity, pH), were used as indicators of change to benthic

fauna habitat (Hedge & Kriwoken 2000). More recent studies include, carbon and nitrogen recycling in tidal mudflats of south-east Tasmania (Cook 2002; Cook *et al.* 2004a; Cook *et al.* 2004b; Cook *et al.* 2004c; Cook *et al.* 2009); an examination of organic carbon in saltmarsh sediments with an emphasis on the invasive *S. anglica* in the Rubicon Estuary and Tamar River (northern Tasmania) (Beasy & Ellison 2013; Sheehan & Ellison 2014; Ellison & Beasy 2018); an extensive study on the saltmarsh/ woodland environmental gradient focusing on soils, terrestrial invertebrates and vegetation at Moulting Lagoon (east coast Tasmania) (Aalders 2014); an analysis by Heyzer (2015) of chironomid fly diversity and tolerance to various soil conditions (e.g. pH and salinity) in south-east Tasmania; interpreting European impacts from a saltmarsh soil core at Little Swanport (east coast) (Moss *et al.* 2016); and the relationship of soil pH and conductivity to invertebrate distributions along the saltmarsh to hinterland gradient in south-east Tasmania (Adams 2016).

4.1.4 Study aims

This chapter aims to survey and summarise the range of soil conditions present in Tasmanian coastal saltmarshes. Data from comprehensive field sampling will be classified into groups, then be explored for any relationships to natural, pre-existing regionalisation, plant communities and climate variables.

Study aims include:

- Classification and grouping individual field-plot edaphic factors using hierarchical agglomerative methods;
- Investigation of edaphic factors of individual groups formed from clustering and test for differences between those groups;
- Examination of climate variables of individual soil types and test for differences between soil types;
- Investigation of the relationship between various regionalisation types (from Chapter 1: Regionalisation of Tasmanian natural areas) to establish if any regionalisation can be a precedent for soil types, and if so, test for differences between individual regions;

- Alignment of soil types to plant species and determine species indicators for each soil type; and
- Alignment of vegetation communities (previously identified in Chapter 3: Classification of coastal saltmarsh vegetation of Tasmania) to edaphic factors, determine the edaphic factor range of each vegetation community and test for differences between communities.

Note: this Chapter does not consider edaphic factors and individual plant species. This topic is addressed in Chapter 6: Saltmarsh plant species tolerance to edaphic factors and climate variables.

4.2 Methods

The term "edaphic factor(s)" is used throughout the following as the descriptor of soil characteristics. The word "factor" is used to differentiate other site characteristics such as climate, where the collective word used is "variable", or in vegetation, where "community" is used as the collective term.

4.2.1 Site locations

The locations/sites/plots used for soil sampling and assessment are detailed in Chapter 2 (Defining Tasmanian coastal saltmarshes and description of study sites) and are those that were assessed for vegetation and reported in Chapter 3. This will enable direct comparison between vegetation community type and soil characteristics in the following text and chapters (Chapter 5: Carbon stock of Tasmanian saltmarshes and Chapter 6).

4.2.2 Field work

Field work for soil sampling was conducted over a 24-month period, often in conjunction with vegetation assessments.

Bare ground

The bare ground component of each plot was estimated as a percentage of "cover" (e.g. Figures 4.1 to 4.3) and scaled as follows:

0 = not present, 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = >75%.

The estimation, a visual appraisal conducted during vegetation assessment, was by the same assessor to provide uniformity.

Figure 4.1 (top left): Bare ground cover class 0 (bare ground not present).

Figure 4.2 (above): Bare ground cover class 3 (5-25% presence).

Figure 4.3 (left): Bare ground cover class 5 (50-75% presence).

Soil sampling

Soil samples were collected from each field-plot during vegetation assessments. As study sites were very widespread along the Tasmanian coastline and off-shore islands (see Chapter 2, Section 2.2, Figures 2.36 to 2.39) it was difficult to collect soil samples concurrently. Tides, floods, access to the sites, particularly those that required access by air or ferry, all compounded to make soil sampling a difficult and very laborious task. Furthermore, as this study was conducted in three phases (Training, Test 1 and Test 2), collection of soil material was spread over a 24-month period, which may complicate comparisons between sites. Another issue was the sampling of sites at a similar tidal cycle, whether it be a falling or rising tide, or during astronomical (spring/neap) tides. This was further complicated during periods of high or low rainfall which can impact soil moisture and salinity levels. Every effort was made to collect soil samples within a two-hour window centred on a neap low tide. This improved consistency for many plots in respect of moisture, as by low tide, most surface waters would have drained

from the marsh. In the majority of cases sampling was avoided following storm events which often result in increased tidal inundation and/or increased rainfall, thereby impacting moisture and salinity levels. However, several edaphic factors (e.g. bulk density, soil composition) would unlikely be impacted by weather or timing of soil sampling. Considering the above, all collected data were used in the analysis as it provided a full range within each factor to the conditions experienced at study sites and an insight to the tolerance of individual plant species found in coastal saltmarshes.

Two types of samples were collected from each study plot – a) a "core" of the top 10cm layer (the "A" sample from each study site) (Figure 4.4); and b) a sample to at least 20cm, and deeper if organic matter was still evident at the 20cm mark (the "B" sample) (Figures 4.5 and 4.6). The focus of the "B" sample was analysis of the "growing medium" material. Note: in several cases it was not possible to determine the extent of the organic layer due to the depth of that layer. Three sub-samples of each type ("A" and "B") were collected within the represented area of the plot (restricted to the vegetation group that being assessed) and the three "B" sub-samples aggregated to form the "B" sample.

Figure 4.4: Examples of "A" soil sample (core). The brown bar between the cores is 10cm, the organic layer depth is 7cm. The two cores are those from Figure 4.9 (below).

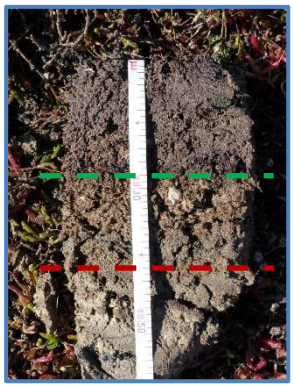


Figure 4.5: A "B" soil sample. The organic layer depth is 9cm, sand/shell thickness is 5cm, followed by sand.

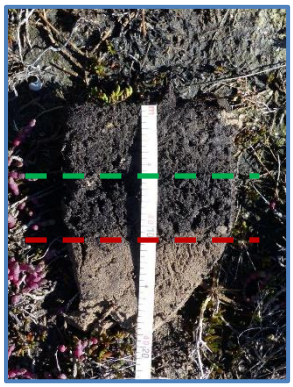


Figure 4.6: A "B" soil sample. The organic layer depth is 6cm, anaerobic thickness is 5cm, followed by sand.

The "A" sample was obtained by carefully hammering into the ground a numbered, pre-weighed 10cm section of 7cm diameter PVC tube. A fitted cap was placed over the tube when inserting into the ground so as not to compress the soil within the tube. Once the top of the tube was level with the surface of the ground it was carefully removed so that the "plug" (importantly the bottom) was undisturbed. This was

immediately wrapped in plastic film and transferred to an insulated, closed box to prevent drying (Figures 4.7 to 4.9).

Figure 4.7: PVC tube and protection cap used when driving tube into ground to minimise compression of soil in the tube.

Figure 4.8: PVC tube inserted into soil strata.

Figure 4.9: PVC tube removed from soil and enclosed in plastic wrap.

The "B" samples were simply dug from the ground using a spade and trimmed to fit the storage containers. The organic growing medium/section in which roots were present, this identified as the O-layer (McDonald & Isbell 2009), was transferred to a plastic container and appropriately labelled.

On return to laboratory, the "A" sample was weighed and placed in an oven to dry at 105°C, and the "B" sample was air dried in a fume hood using only fan forced air. Oven drying of the "B" sample was not done, this to prevent changes to soil characteristics. Once dried, each "B" sample was sieved on a 2mm sieve with large pieces broken up using a mortar and pestle (if possible) prior to sieving. Care was taken to remove any obvious plant material from the sample. The <2mm fraction was packaged in sealed plastic boxes, labelled and stored.

A small sub-sample of each "B" sample has been archived in 70ml vials *(n* = 407) and all are currently stored at the University of Tasmania, Sandy Bay campus.

The laboratory analysis of soil moisture content (by volume and by weight), bulk density, soil chemistry (pH and EC/salinity), and soil organic matter by loss on ignition of the <2mm fraction from each "B" sample (growing medium), was undertaken by the author. The methodology used in the statistical analysis of the data is outlined in Section 4.3 (below).

Organic layer

The depth of the organic layer of each of the three "B" sub-samples in each plot was

recorded to 0.5cm (Figure 4.10), and the mean (of the three sub-samples) became the organic (or O) layer depth (McDonald & Isbell 2009) for each plot.

Figure 4.10: Organic layer depth – plot from Lutregala Marsh, Bruny Island. The peat layer, which is the total O layer thickness (16cm), is also the root zone. The substrate was comprised of a clay/silt layer (smudgy grey colour, 1.5cm thick) which overlayed the sand (light grey/white). The sub peat layer is often anaerobic. This is an example typical of many saltmarsh soils particularly on the eastern coast of Tasmania and is generally indicative of saline succulent vegetation. Deeper organic layered soils are found in southern and western locations and are primarily composed of decomposed vegetation matter and roots. These are usually indicative of saline rushland vegetation.

4.2.3 Laboratory analysis

Soil moisture content

Soils can hold substantial amounts of moisture, yet moisture content is often over-looked or ignored in environmental studies (Rayment & Lyons 2011). As moisture is an important feature in saltmarshes, it has been used as one of the factors in the characterisation of soils in this study. The cyclical rise and fall of tides, floods and drains water from the marsh and moisture retention is determined by the soil structure (Long & Mason 1983). Soils containing high levels of organic matter can retain over 10% of their oven dried weight as moisture, whereas those with low levels of organic matter such as siliceous sands retain less than 2% moisture (Rayment & Lyons 2011). Waterlogging in saltmarshes is a major factor in saltmarsh ecology (Adam 1990), its major impact is limiting the supply of oxygen and allows the soil to become anaerobic (Long & Mason 1983). Variation in plant species capacity to tolerate anaerobic conditions and high levels of salinity caused by tides, determines plant species distribution within saltmarshes (Long & Mason 1983; Adam 1990). Furthermore, waterlogging impacts the reducing potential of saltmarsh soils which can lead to the production of volatile organic compounds such as methane (Long & Mason 1983).

Following weighing on receipt at the laboratory, the "A" sample from each plot was initially oven dried at 105^{o}C for 24 hours. Next, the soil core was removed from the PVC tube, cut in half longitudinally (to aid complete drying), weighed and returned to the oven for further drying (Figures 4.11 and 4.14).

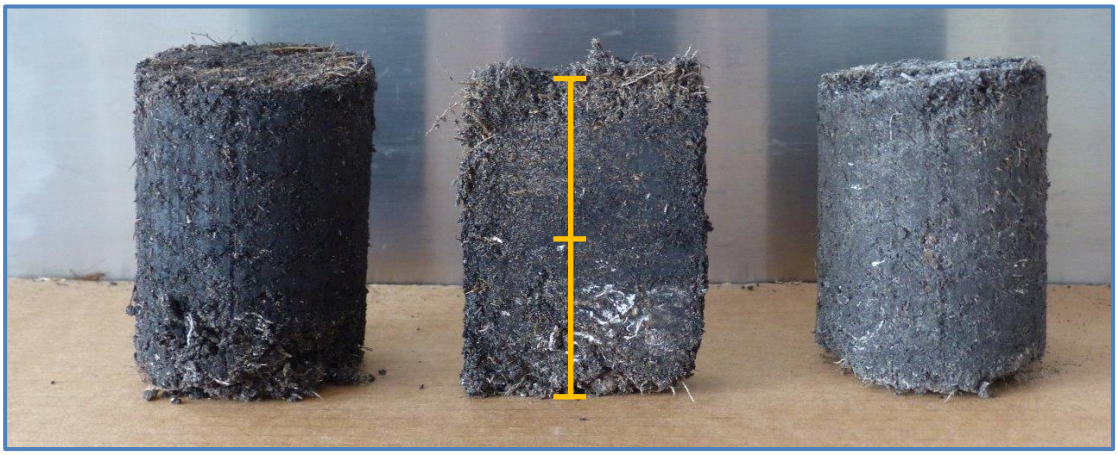


Figure 4.11: Soil core sample from a *Gahnia filum/Lawrencia spictata/Disphyma crassifolium* (AGH) community. The sample on the left (complete core) is a predried example (573g), the dried sample on the right, dried to a stable weight of 374g, thus moisture by volume = 36.4%, by weight = 28.7%, bulk density = 0.894g/cm3. The face sample (centre) is classed as loamy-soil 4 (51-75%), sand 2 (11-25%), shell 1 (1-10%), roots 1 (1-10%).

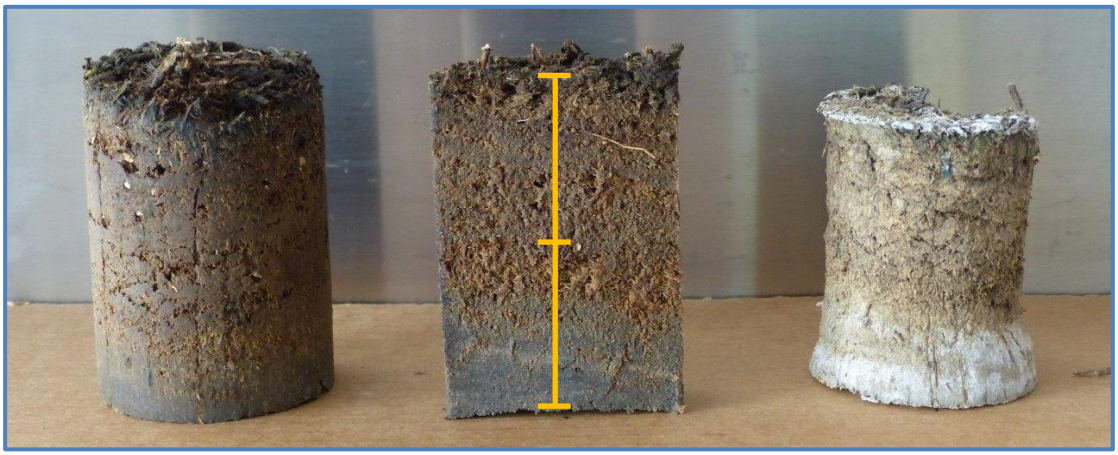


Figure 4.12: Soil core sample from a *Sarcocornia quinqueflora/Samolus repens* (AQR) community. The sample on the left (complete core) is a predried example (449g), the dried sample on the right, dried to a stable weight of 116g, thus moisture by volume = 69.3%, by weight = 71.9%, bulk density = 0.260g/cm3. The face sample (centre) is classed as peat 4 (51-75%), clay 3 (26-50%), roots 1 (1-10%), sand 1 (1-10%).

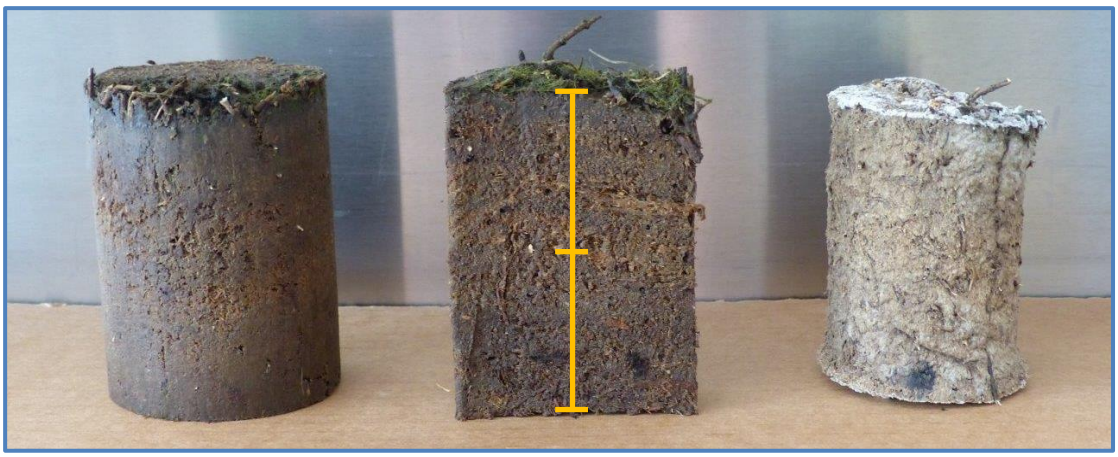


Figure 4.13: Soil core sample from a *Tecticornai arbuscula/Sarcocornia quinqueflora* (ASH) community. The sample on the left (complete core) is a predried example (494g), the dried sample on the right, dried to a stable weight of 82g, thus moisture by volume = 88.7%, by weight = 82.6%, bulk density = 0.177g/cm3. The face sample (centre) is classed as peat 5 (>75%), clay 2 (11-25%), roots 1 (1-10%).

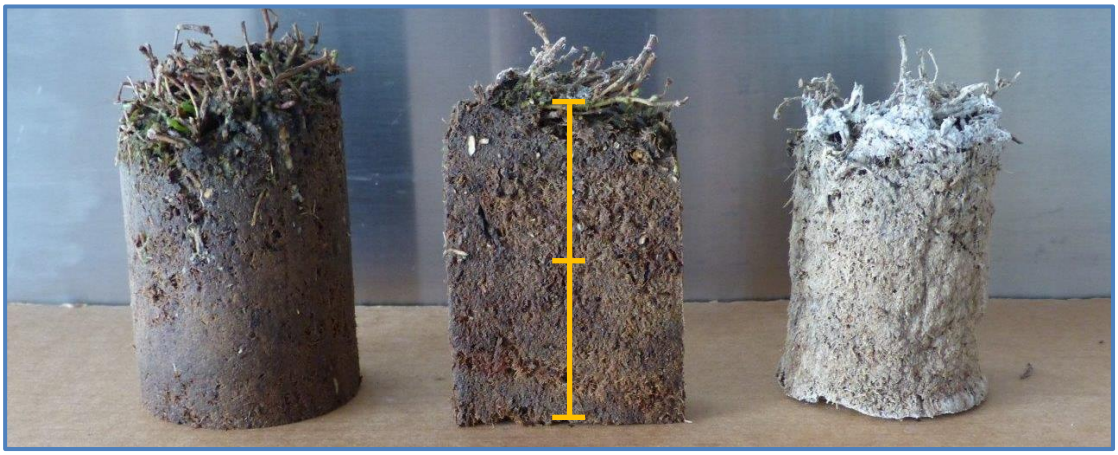


Figure 4.14: Soil core sample from a *Sarcocornia quinqueflora* (ASQ) community. The sample on the left (complete core) is a predried example (463g), the dried sample on the right, dried to a stable weight of 64g, thus moisture by volume = 83.4%, by weight = 85.7%, bulk density = 0.113g/cm3. The face sample (centre) is classed as peat 5 (>75%), roots 1 (1-10%).

In each of the 4 figures (above) the orange bar is 10cm, the midpoint crossbar at 5cm.

The core samples were weighed at approximately 12-hour intervals and were considered dry once weight had stabilised. The dried sample provided: a) soil moisture by weight (%); and b) soil moisture by volume (%). Soil moisture by volume is the more important variable as it provides a more accurate reflection of moisture content as it is measured against a fixed measure, volume. When moisture is measured by weight, the moisture content is measured against the solid portion which can be composed of various materials, such as peat, roots or sand, in differing combinations and proportions, therefore not a uniform measure for comparison in terms of moisture.

Soil bulk density

Soil bulk density (SBD) has been defined as the ratio of the oven-dried mass of a soil sample to the bulk volume of that same sample (Blake 1965; Ruehlmann & Körschens 2009). This measure is widely used and is required to estimate, evaluate and calculate many physical properties of soil which include water retention, porosity, compressibility and heat retention (Blake 1965; Ruehlmann & Körschens 2009). Of all soil characteristics, the most dominant determining factor of SBD is soil organic matter (Gosselink *et al.* 1984). Bulk density can change according to soil's structural condition, therefore is often used as a measure of soil structure (Blake 1965). The most common technique of determining soil bulk density is to press a non-flexible ring of known volume into the ground and, following drying, determine its weight (McKenzie *et al.* 2004). Organic rich soils usually have a SBD of less than 0.5g/cm^3, while silts and clays

range 1.1 to 1.6g/m^3, and sand 1.3 to 1.7g/m^3 (Pluske *et al.* 2016), however, SBD will depend on total composition (peat + silt/clay + sand in any combinations) of the sample.

Soil bulk density for each "A" sample was calculated by dividing the dry weight of the soil core by its volume and expressed as grams per cubic centimetre (g/cm^3):

$$\text{Bulk Density (g/cm}^3\text{)} = (W_{Soil\&SoilCore}\ (g) - W_{SoilCore}\ (g)) \,/\, Vol_{SoilCore}\ (cm^3) \qquad (4a)$$

Where:

$W_{Soil\&SoilCore}$ = weight (grams) of oven dried (to 105°C) of soil core (PVC tube) and soil sample,

$W_{SoilCore}$ = weight (grams) of soil core (PVC tube),

$Vol_{SoilCore}$ = volume (cm^3) of the soil core.

Soil chemistry (EC/salinity and pH)

The distribution of vegetation in a saltmarsh can be influenced by acidity (Wherry 1920), and the concentration of salt within the soil (Álvarez-Rogel *et al.* 1997; Álvarez-Rogel *et al.* 2000). With increasing elevation, flooding tides decrease, although this it is not necessarily synonymous with salinity (Adam 1990). Salinity levels can vary spatially and temporally throughout saltmarshes (Álvarez-Rogel *et al.* 1997). Precipitation between tidal flooding can reduce salinity, yet during periods of dry weather, salinity levels can increase due to evapotranspiration (Long & Mason 1983; Adam 1990) resulting in salinity levels greater than that of seawater (personal observations). The elevated terrestrial profile is also subject to high levels of aerosolic salt borne by strong onshore winds thus increasing soil salinity levels (Long & Mason 1983).

EC/Salinity

Salinity levels in soils are usually assessed by measuring the electrical conductivity (EC) of a soil/water solution (Hazelton & Murphy 2007), this converted to a salinity value, often within the same measuring device. The EC of a soil solution is directly related to the amount of total dissolved salts that are present in the soil. Currently, there is no internationally agreed technique for determining EC in soil, the main option being a soil/water ratio of 1:5 which is widely used in Australia (Rayment & Lyons 2011). The common units for EC are, dS/m and salinity, parts per thousand (ppt or ‰), these

units have been used throughout this study. Soil chemistry tests used to determine EC/salinity content are from (Rayment & Lyons 2011) described below.

EC/Salinity 1:5 soil and water: three sub-samples from "B1" soil sub-sample (*n* = 1,221) were prepared and tested by adding ten grams of air dried soil to 50ml of deionised (DI) water and placed in a flask. The solution was mechanically shaken for one hour to dissolve soluble salts (Figure 4.15).

Figure 4.15: Chiltern flask shaker.

After standing for 20-30 minutes to allow solids to settle, three EC/salinity readings were taken using a temperature compensated pre-calibrated Hanna Instruments EC/TDS/NaCl/Resistivity meter (model HI 98192), thus nine readings were taken for each sample (3 readings from 3 sub-samples). An average was calculated from the nine readings, this became the EC/Salinity 1:5 value of each "B1" sub-sample, reported as: EC (dS/m)/salinity 1:5 (‰) at 25°C on an air dry (40°C) basis. Several samples were repeated to reduce the coefficient of variation (CV) (standard deviation/mean of a sample). In a small number of cases (*n* = 24, 5.9% of the 407 samples), this could not be achieved as not enough material was available for continued analysis. The mean of the final CV for all samples was 4.71%, an indication of the precision of the results.

pH

The pH measure of soil is its value of the acidity or alkalinity, indicating the chemical activity of the hydrogen ion and/or the hydroxyl ion in a water solution (Hazelton & Murphy 2007; Rayment & Lyons 2011). This chemical activity is at its lowest when the pH value is 7.0. Soil pH plays an important role in the distribution of native plants (Wherry 1920). Saltmarsh soils that undergo regular inundation become anaerobic leading to the release of sulphides, which when oxidised, form sulphates that cause the lowering of pH (Adams 1963). Soil pH is generally measured in deionised water or a 0.01M calcium chloride ($CaCl_2$) solution, at a ratio of one part soil to five parts solution

(Hazelton & Murphy 2007). The use of a $CaCl_2$ solution is recommended for soils that have been affected by salts such as sodium from sea water (Rayment & Lyons 2011), as calcium readily displaces exchangeable aluminium ions which then hydrolyses in the solution (ASTM 2011), thus providing an equitable basis for each sample.

pH of 1:5 soil/0.01M calcium chloride ($CaCl_2$): this method was used as the results are largely unaffected by the occurrence of soluble salts, due to the presence of $CaCl_2$ solution. Three sub-samples from each "B1" soil sub-sample *(n* = 1,221) were prepared and tested as follows: ten grams of air dried soil was added to 50.0g of 0.01M $CaCl_2$ and placed in a flask. The solution was mechanically shaken for one hour. After standing for 20-30 minutes to allow solids to settle, three pH readings were taken using a temperature compensated pre-calibrated Hana Instruments soil pH meter (model 99121). Thus, nine readings were taken for each sample (3 readings from 3 sub-samples). An average was calculated from the nine readings and nominated as the pH value for each sample, reported as pH (1:5 soil/0.01M $CaCl_2$) on an air-dry basis. No samples had to be repeated as all CV values were below 2.5%, and the mean of the final CV for all samples was 0.28%.

It is noted that analysis for EC/salinity and pH were separate procedures, as methods used were not compatible for a single analysis of EC and pH (EC/salinity used deionised water, whereas pH used a 0.01M $CaCl_2$ solution).

A note on calibration: Prior to use each day, each meter (EC/salinity and pH) was calibrated using EC/salinity buffers of 1.413, 12.88 and 111.8 dS/m and 5, 20 and 40‰, and pH buffers of 4.0, 7.01 and 9.21. Calibrations were checked prior to measurement using all three EC/salinity buffers, and pH buffers of 4.0 and 7.01 as this was the expected range of the soil measurements. The meters were checked during measurements and recalibrated whenever necessary.

Composition

Globally, saltmarsh soil composition varies considerably. Around Britain, most coastal sediments are composed of highly variable glacially deposited material (Adam 1990). In many parts of the wold, coastal shoreline sediments are made up from eroded soils from clearing of inland areas following European settlement (Adam 1990). In the Bay of Fundy (West Canada) records show that saltmarshes overlay the remains of pine and

beech forests, while in parts of England, soil high in clay and silts rest on a gravel base (Long & Mason 1983). Rates of composition of sand, silts and clays varies considerably; sites can range from 5% sand to over 70%, while others, for example in North Carolina, can range from 40% to over 90% sand (Long & Mason 1983). Likewise, in the Susitna marshes of Alaska, soil texture varies greatly across and between sites in the area with some points recording 38% silt and 34% sand (Vince & Snow 1984). Roots and rhizomes of saltmarsh plants are generally shallow and are mostly present in the upper 15cm of the soil stratum. The root to shoot ratios of saltmarsh plants range from 1.4 to 50, therefore primary production in the sub-surface biomass can contribute to extensive deposits of organic material below ground (Long & Mason 1983; Chmura *et al.* 2003).

There is little record in the literature of assessing rather than measuring (by way of particle size analysis) the composition of saltmarsh soils; hence the following was applied to all "A" samples. Once dried, each sample was visually assessed for peat, sand, loam/soil, clay, shell and roots (see Figures 4.16 to 4.18 pages 4.10 and 4.11 for examples) and scored as follows:

0 = <1%, 1 = 1-10%, 2 = 11-25%, 3 = 26-50%, 4 = 51-75%, 5 = >76%.

The results were entered to an MS Excel spreadsheet for later statistical analysis.

Soil organic matter

Soil organic matter (SOM) in the saltmarsh environment is sourced from either tidal-borne material (Adam 1990) or decaying vegetative matter that grows on the marsh in addition to roots and rhizomes that support the vegetative growth (Long & Mason 1983). Saltmarsh SOM does not decompose quickly due to poor drainage which inhibits microorganisms' ability to break down plant residues (Rayment & Lyons 2011), leading to increased levels of plant material in saltmarsh soils.

Soil scientists, geographers and geologists have used loss on ignition (LOI) for many years as a reliable technique in the measurement of SOM (Konen *et al.* 2002). It is a safe, quick and relatively cheap process (Craft *et al.* 1991; Navarro *et al.* 1993; Chatterjee *et al.* 2009; Pribyl 2010) and requires simple laboratory equipment (Rayment & Lyons 2011). The method has been described as one of the more accurate methods of

assessing SOM in soils (Navarro *et al.* 1993; Chatterjee *et al.* 2009), yet, it does have some limitations with the accuracy of the result being dependent on a number of factors such as the dryness of the sample, the temperature of the furnace, the sample's composition (Pribyl 2010), the loss of structural water from carbonaceous materials (clays) and CO_2 from soil carbonates (Navarro *et al.* 1993; Chatterjee *et al.* 2009).

The procedure for LOI adopted in this research is a combination of Soil and Plant Analysis Council (1999) and Rayment and Lyons (2011), slightly modified. Each sample *(n* = 407) was dried in an oven at 105°C for 12 hours to remove any residual moisture, then following weighing in a crucible, was ashed at 550°C for three hours in a muffle furnace (Woodrow Kilns, model Hobby Fire Mini, maximum settable temperature 1280°C) fitted with a digital temperature display, a thermostatic temperature control and a settable timer (Figure 4.16). Examples of pre and post ashing are displayed in Figures 4.17 and 4.18).

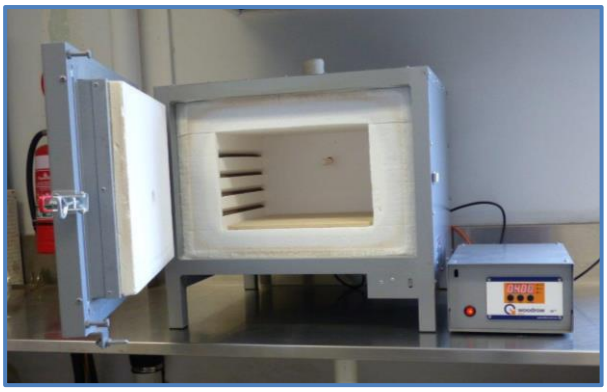
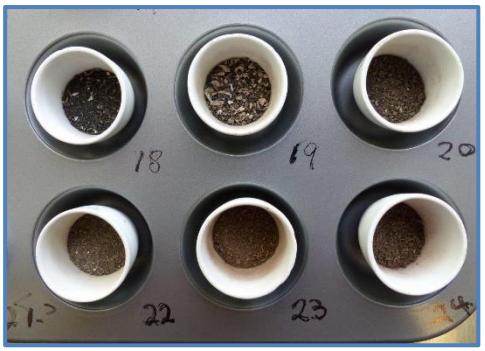


Figure 4.16: Above – muffle furnace.



Figures 4.17 – 4.18: Top – pre-ashing in furnace. **Bottom** – post ashing (same samples).

Following cooling in the furnace to between 250-280°C, approximately 4-6 hours, the samples were reweighed still in their respective crucibles and once emptied, the crucible was also weighed.

The organic matter component of the soil was calculated as follows:

$$\%LOI = [((W_{105} - \text{Crucible 1}) - (W_{550} - \text{Crucible 2})) \times 100] / W_{105} \quad (4b)$$

Where:

W_{105} = weight of crucible and oven dried (to 105°C) sample, pre-ashing,
Crucible 1 = weight of the crucible pre-combustion at 550°C,
W_{550} = weight of crucible and sample post ashing,
Crucible 2 = weight of the crucible post combustion at 550°C.

The result is reported as LOI at 550 (%) on an oven dry basis.

The procedure was repeated with ashing at 850°C (to ash carbonates (inorganics) as well as organic matter) for three hours, followed by cooling in the furnace for approximately 6-8 hours to 260-280°C prior to removing from furnace and reweighing. The organic and inorganic matter component of the soil was calculated as follows:

$$\%LOI = [((W_{105} - \text{Crucible 3}) - (W_{850} - \text{Crucible 4})) \times 100] / W_{105} \quad (4c)$$

Where:

W_{105} = weight of crucible and oven dried (to 105°C) sample, pre-ashing,
Crucible 3 = weight of the crucible pre-combustion at 850°C,
W_{850} = weight of crucible and sample post ashing,
Crucible 4 = weight of the crucible post-combustion at 850°C.

The result is reported as LOI at 850 (%) on an oven dry basis.

A study by Heiri *et al.* (2001) considered whether the position within the furnace and the size of the sample affected LOI results. To see if this had a bearing on the LOI values and reproducibility/precision of the results of this research, each sample was replicated three times *(n* = 1,221) during each LOI process (at 500°C and 850°C, therefore a total of 2,442 sub-samples were replicated) using different weights, in different size crucibles (surface area) and placed randomly in the furnace. Little variation in results was observed in respect to position in the oven, however, sample size was restricted to 2-3 grams as determined by validation tests (this further reported in Chapter 5).

In respect of LOI at 550°C (from herein LOI550), several samples *(n* = 35) were repeated to reduce the CV to below 10%, this a decision point on when "enough is

enough". In six cases (1.5%), this could not be achieved even though several samples were ashed 15 times. This is perhaps due to the very low SOM content in two samples, both being principally composed of sand. The mean of the final CV for all samples was 2.77% an indication of the high precision in the results.

Regarding LOI at 850°C (from herein LOI850), a few samples *(n* = 37) were repeated to reduce the CV to below 10%. In just three cases (0.75%), this could not be achieved, perhaps again due to the very low SOM content of these samples, being principally composed of sand. The mean of the final CV for all samples was 2.99%, again, an indication of the high precision in the results.

4.2.4 Climate

Climate variables, comments and data, provided in Chapter 3 (see Section 3.3.4), were applied to this Chapter and aligned with saltmarsh soil data and results.

4.2.5 Regionalisation/Classification

Various types of regionalisation used in Tasmania have been outlined in Chapter 1 (see Section 1.2). Of these, IBRA6.1, IMCRA3.3, Bureau of Meteorology (BOM) coastal districts, geographic (Edgar *et al.* 1999) and estuarine classification (Edgar *et al.* 1999) have been identified as suitable, either through strong coastal connections or clearly related to estuarine systems, for further investigation in relation to edaphic factors.

4.2.6 Group indicator plant species

In this component, the edaphic factor dataset was used to cluster the plots into groups of soil types, and then the vegetation dataset (from Chapter 3) was used to determine the indicator species for each soil type. The species indicator analysis used the Braun-Blanquet cover abundance values transformed to average cover following the removal of values 1 (<1%) and 2 (1 to 5%). This was justified as minor/rare species may have an adverse impact on the true results of the indicator species analysis, as minor/rare species often have limited or no significance within an ecological community (Clarke & Warwick 2001).

4.2.7 Vegetation communities

Vegetation communities were previously determined in Chapter 3. Edaphic factors were aligned to individual vegetation communities, then statistically analysed to extract

any relationships between the vegetation communities and individual edaphic factors.

4.3 Statistical analysis

4.3.1 Correlation between edaphic factors

The relationship between edaphic factors was tested using the correlation (cor) function in R, this to identify predictor variables that would be useful tools in the laboratory and the field. Correlation was tested among all factors.

4.3.2 Classification to groups

This topic has been outlined and fully discussed in Chapter 3 (Section 3.3.2) where the final vegetation classification used the hierarchical method of Flexible β to classify vegetation communities to eight groups. To maintain continuity in this study, the same classification method is used to classify the soil data to eight soil type groups.

Individual edaphic factors, bare ground, O layer depth, pH, EC, moisture by volume (%), bulk density (g/cm^3), LOI550 and LOI850 (%), and composition of peat, sand and loamy-soil, were used to classify coastal saltmarsh soil type.

Dendrograms

A standard dendrogram from Flexible β clustering was produced, this cut at eight soil types.

Grouping

The eight soil types were allocated a numerical value (1, 2 etc.) based on the order of the hierarchical clustering.

4.3.3 Soil type groups

Individual edaphic factors were aligned to each soil type formulated from the hierarchical clustering. Once associated, the soil type group edaphic factors were analysed using multivariate methods in the `vegan` package of R to:

- Examine the attributes of each soil type (group) by use of boxplots summarising quartiles; and
- Check for differences of group means using analysis of variance (ANOVA). A post hoc test, Tukey's Honestly Significant Difference (HSD) test, was used to

identify those soil types that differed significantly from each other.

4.3.4 Climate variables

Climate data were aligned to each soil type and once associated, the soil type climate data were analysed using similar multivariate methods as outlined in the previous Section (see 4.3.3 – above).

4.3.5 Indicator plant species

The indicator species analysis is an aid that enables recognition of vegetation community structure. This topic has been outlined and fully discussed in Chapter 3 (Section 3.3.5) where individual plant species were aligned to individual vegetation communities.

4.3.6 Regionalisation types

Individual edaphic factors were aligned to each selected regionalisation types and the estuarine classification. Once associated, the edaphic factors were analysed using multivariate methods in the vegan package of R to:

- Examine and compare the soil attributes of individual regions/classification by use of boxplots summarising quartiles; and
- Check for differences of group means using ANOVA. Tukey's HSD test was used to identify those groups that differed significantly from each other.

ANOVA results were examined for the first, second and third highest F values of the regionalisations/classifications, and a ranking value applied to each to allow an objective determination of the best fit between regionalisation type and coastal saltmarsh edaphic factors.

4.3.7 Vegetation communities

This section integrates the previously determined vegetation community groups (see Chapter 3) with edaphic factors and evaluates outcomes.

Individual edaphic factors were aligned to each vegetation community. Once associated, the community edaphic factors were analysed using multivariate methods in the vegan package of R to:

- Examine the soil attributes of each vegetation community by use of boxplots summarising quartiles; and
- Check for differences of (vegetation community) group means using ANOVA. Tukey's HSD test was used to identify those communities that differed significantly from each other.

4.4 Results and discussion

The following section incorporates a combination of both results and discussion, because some results require comment before progressing to a subsequent result. Within the following text, organic layer depth values are expressed as cm (centimetres), pH values are standard pH units, EC values as dS/m (decisiemens per metre), bare ground cover, moisture, composition (peat, sand, loamy-soil), LOI550 and LOI850 all by % (percent), SBD as g/cm^3 (grams per cubic centimetre), rainfall as mm (millimetres), temperature as ^oC (degrees centigrade) and solar exposure as MJ/m^2 (megajoules per square metre). All means are reported to standard error. **Note:** the term range, which is used to describe the minimum and maximum values (the limits) of an observation (e.g. pH 6.56 to 7.26, or EC 14.3 to 21.4), and the term spread, used to describe the difference between the limits (the extent) of an observation (e.g. from above, 0.70 or 7.1) are presented as pH 6.56-7.26, 0.70, or EC 14.3-21.4, 7.1. Results have been comprehensively reported.

4.4.1 Correlation between edaphic factors

Correlation between individual edaphic factors are tabled in Table 4.1. The strength of correlation is presented in Table 4.2.

Most correlations were weak (<0.6); a mediocre correlation (0.6 to 0.8) existed between:

- Bulk density and LOI550, LOI850, peat and sand; and
- EC and bulk density, LOI850 and peat.

Correlation between both LOI treatments was strong, though that was an expected result as the inorganic soil component of saltmarsh soils was very low. No individual edaphic factor could be categorised as a predictor of saltmarsh soils.

Table 4.1: The correlation between each edaphic factor; 0 to 0.3 (nil symbol) = weakest correlation, 0.95 to 1 (B symbol) = strongest correlation.

Factor	Bar_grd	Depth	pH	EC	M_vol	Bul_den	LOI_550	LOI_850	Peat	Sand	L.soil	Clay	Shell	Roots
Bar_grd	**1**													
Depth		**1**												
pH			**1**											
EC		.		**1**										
M_vol		.		.	**1**									
Bul_den	.	,	.	,	,	**1**								
LOI_550	.	.	.	.	.	,	**1**							
LOI_850	.	,	.	,	.	,	**B**	**1**						
Peat		.	.	,	.	,	.	.	**1**					
Sand	.	.	.	.	.	,	,	,	.	**1**				
L.soil				.					.		**1**			
Clay												**1**		
Shell													**1**	
Roots		.					.	.		.				**1**

0 ‘ ’ 0.3; 0.3 ‘.’ 0.6; 0.6 ‘,’ 0.8; 0.8 ‘+’ 0.9; 0.9 ‘*’ 0.95; 0.95 ‘B’ 1.

Bar_grd = bare ground, **M_vol** = moisture by volume, **Bul_den** = bulk density, **L.soil** = loamy-soil.

Table 4.2: Strength of correlation between edaphic factors. Negative values indicate an indirect correlation, positive values indicate a direct correlation.

Factor	Bar_grd	Depth	pH	EC	M_vol	Bul_den	LOI_550	LOI_850	Peat	Sand	L.soil	Clay	Shell	Roots
Bar_grd	1.00													
Depth	-0.25	1.00												
pH	0.23	-0.44	1.00											
EC	-0.15	0.40	-0.31	1.00										
M_vol	-0.13	0.49	-0.32	0.58	1.00									
Bul_den	0.33	-0.61	0.49	-0.62	-0.73	1.00								
LOI_550	-0.31	0.58	-0.53	0.59	0.52	-0.76	1.00							
LOI_850	-0.32	0.58	-0.48	0.62	0.51	-0.76	0.99	1.00						
Peat	-0.22	0.45	-0.33	0.69	0.53	-0.61	0.51	0.53	1.00					
Sand	0.26	-0.52	0.47	-0.46	-0.49	0.76	-0.62	-0.60	-0.48	1.00				
L.soil	-0.03	-0.06	-0.16	-0.38	-0.16	0.02	0.01	-0.05	-0.55	-0.20	1.00			
Clay	0.12	-0.02	0.04	0.06	0.13	-0.04	-0.09	-0.08	-0.12	-0.20	-0.18	1.00		
Shell	0.00	-0.09	0.23	-0.08	-0.16	0.10	-0.05	-0.02	-0.10	-0.05	-0.07	-0.06	1.00	
Roots	-0.19	0.39	-0.23	0.16	0.29	-0.44	0.39	0.38	0.12	-0.31	0.02	-0.05	-0.07	1.00

Bar_grd = bare ground, **M_vol** = moisture by volume, **Bul_den** = bulk density, **L.soil** = loamy-soil.

4.4.2 Classification to type (grouping)

Dendrogram

A dendrogram of edaphic factors classification, cut to eight soil types at a level of 4.0, is presented in Figure 4.19 and Appendix 4A.1. The result appears acceptable although it is difficult to interpret properly; multivariate analysis provided clearer results.

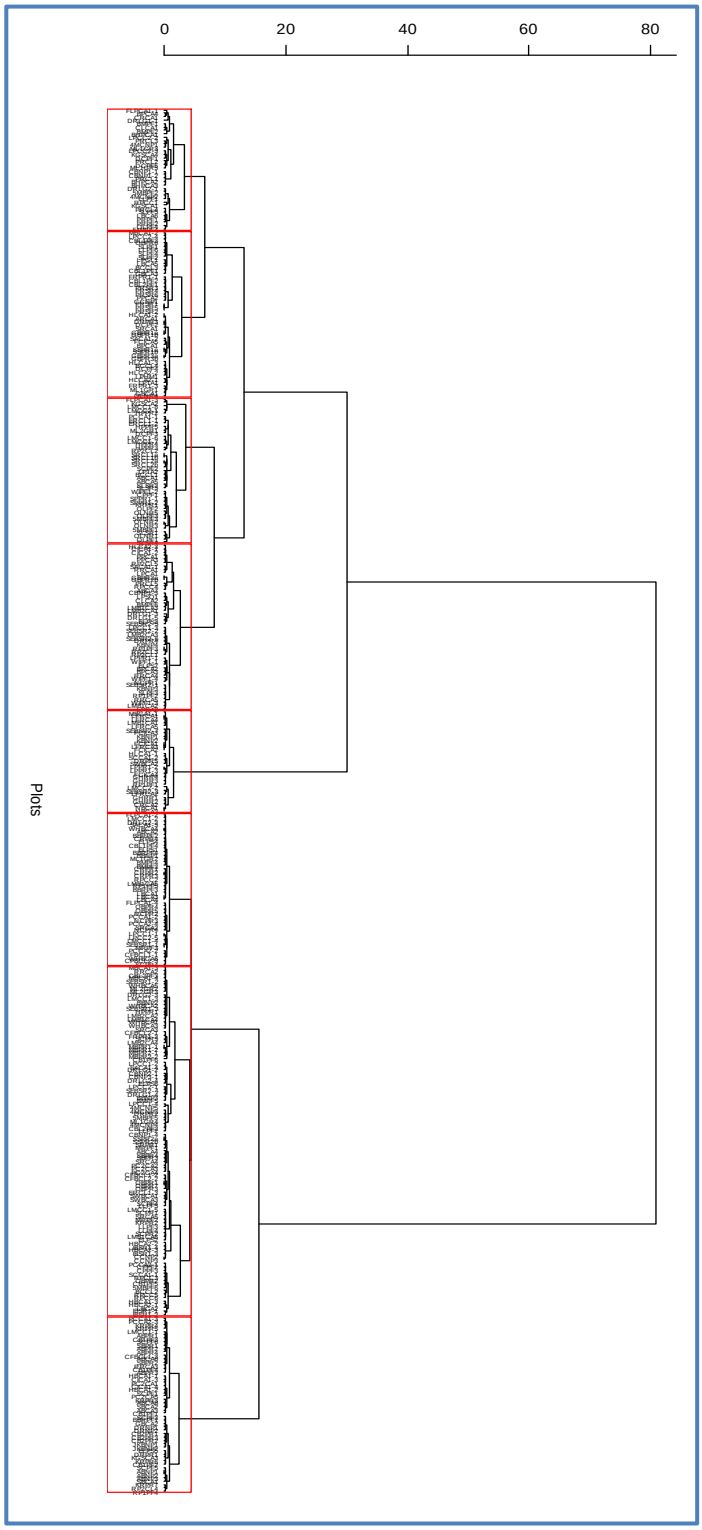


Figure 4.19: Dendrogram of all plots based on edaphic factors and generated from Flexible β clustering using Bray-Curtis dissimilarity measure. The dendrogram has been "cut" to eight soil types at a level of 4.0.

Note: Yes, this figure is not very clear, however, it is provided to demonstrate the grouping attained from clustering. A clearer/larger figure (dendrogram) is provided in Appendix 4A.1.

Grouping

Simple numerical grouping was applied (1, 2 etc.), this based in the order of Flexible β clustering. The number of plots and percentage by soil type is provided in Table 4.3.

Table 4.3: Soil types, number of plots, and percentage of total plots within each type.

Soil type	1	2	3	4	5	6	7	8	Total
No. plots	36	45	43	30	49	103	49	52	407
% of plots	8.8%	11.1%	10.6%	7.4%	12.0%	25.3%	12.0%	12.8%	100%

4.4.3 Soil type groups

The following section focuses on the alignment of soil types (groups) with edaphic factors, climate variables, types of regionalisation and plant species as stand-alone. Note: in this section the terms "soil types" and "soil groups" (which refer to the groups determined by Flexible β clustering) are interchangeable and use is dependent on context within the text to maintain clarity.

Boxplots

Individual edaphic factors, bare ground, O layer depth, pH, EC, moisture by volume, bulk density, LOI550, LOI850, and soil composition characteristics (peat, sand loamy-soil) were aligned to individual soil types and tested using boxplots and ANOVA.

Similar figure pairs, for LOI and soil composition, display the same data range to aid better visualisation of results. Observations on Figures 4.20 to 4.30 are provided with Table 4.5 – Tukey groups. Boxplot data – minimums, 1st, 2nd and 3rd quartiles and maximums are provided in Appendix 4A.2.

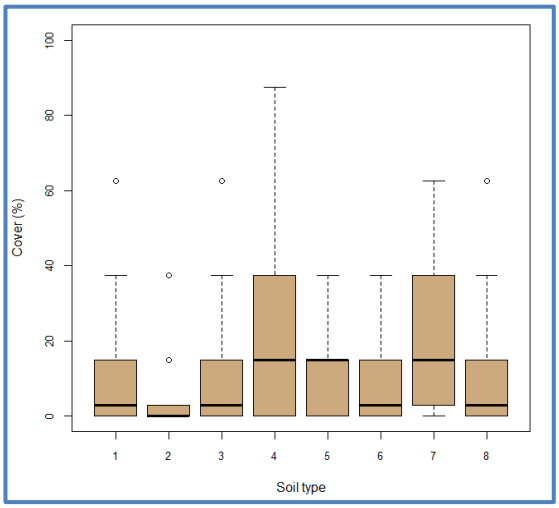


Figure 4.20: Soil type and bare ground.

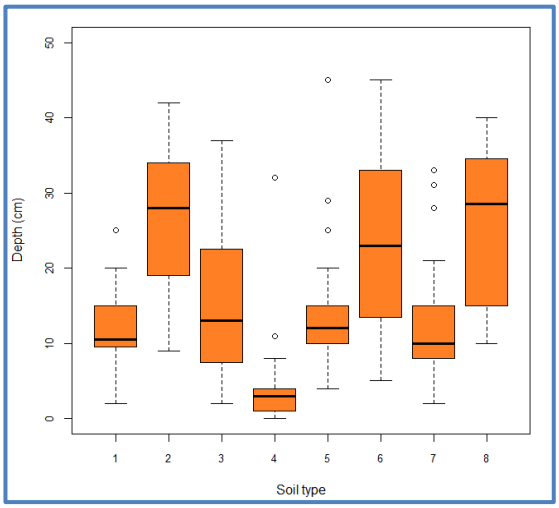


Figure 4.21: Soil type and organic layer depth.

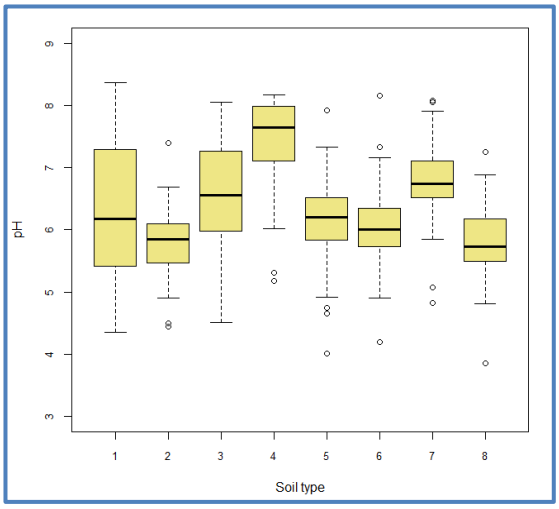


Figure 4.22: Soil type and pH

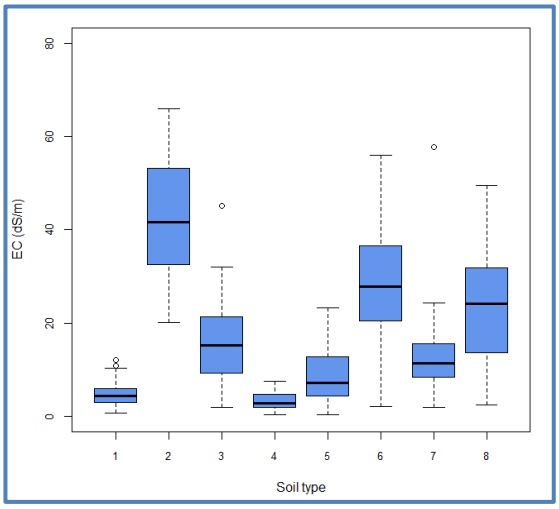


Figure 4.23: Soil type and EC.

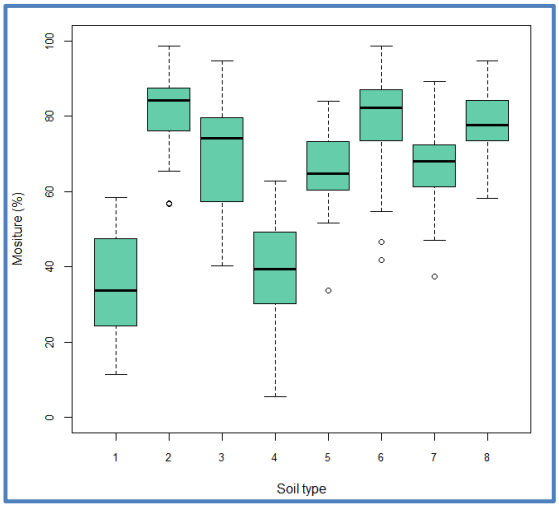


Figure 4.24: Soil type and moisture by volume.

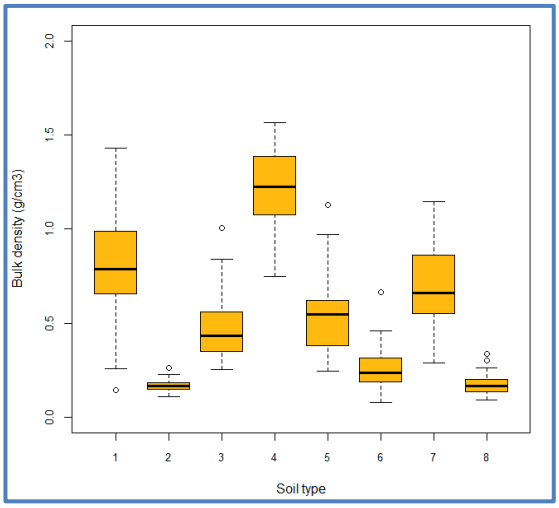


Figure 4.25: Soil type and bulk density.

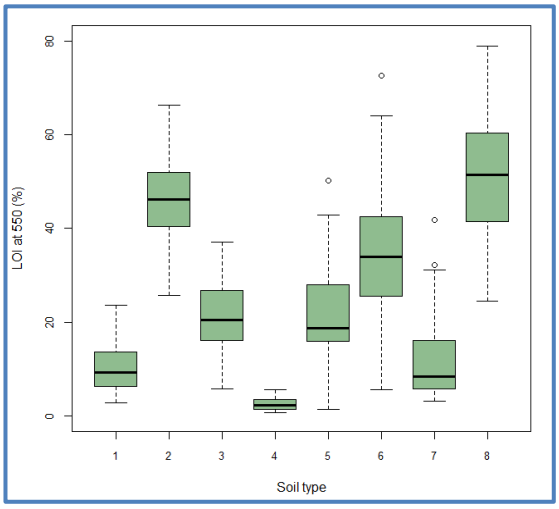


Figure 4.26: Soil type and LOI550.

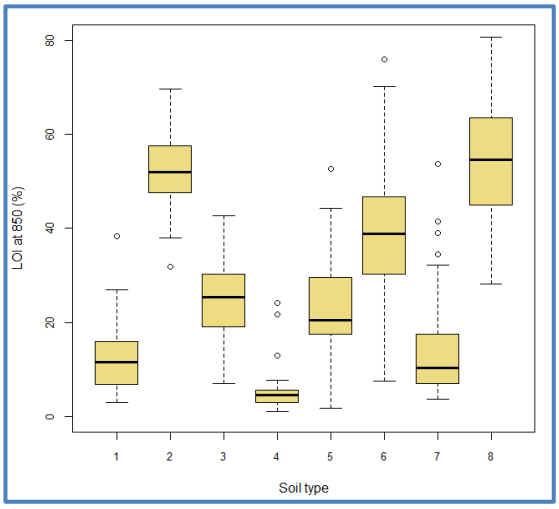


Figure 4.27: Soil type and LOI850.

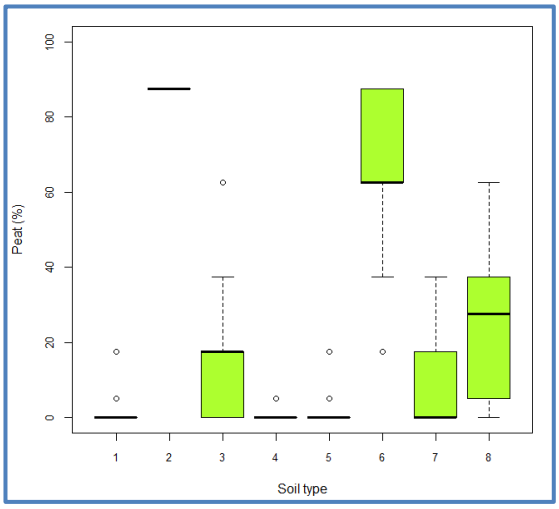


Figure 4.28: Soil type and peat composition.

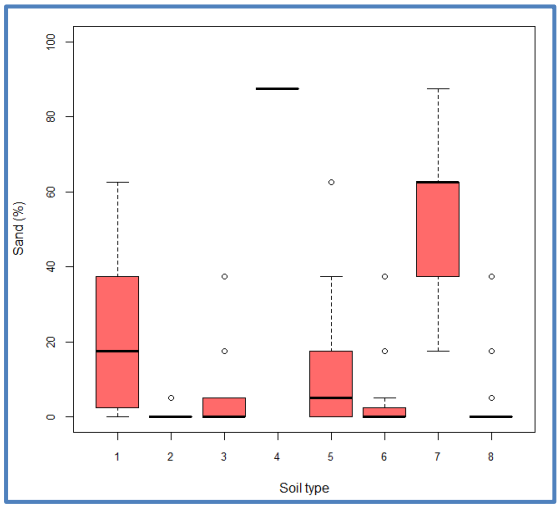


Figure 4.29: Soil type and sand composition.

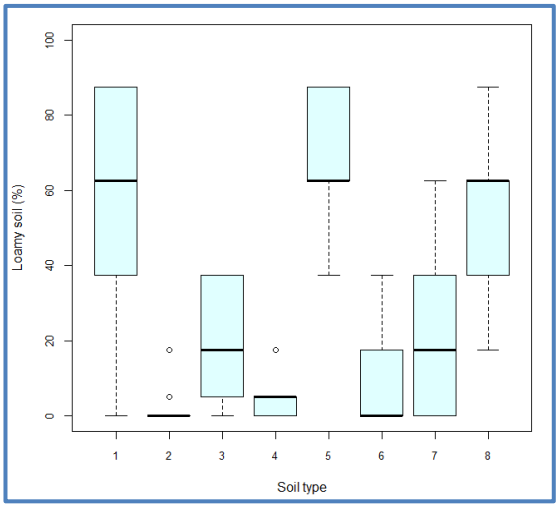


Figure 4.30: Soil type and loamy-soil composition.

Edaphic factors ANOVA

The ANOVA outputs of edaphic factors are presented in Table 4.4 (following page).

All edaphic factors displayed significant differences ($p<0.001$) between soil types. The very low p-value for each indicated that there was at least one soil type within each variable that was significantly different to all other soil types within that variable.

Table 4.4: ANOVA results for soil type edaphic factors – sorted by order of boxplots (see Figures 4.20 to 4.30).

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	7, 399	6.28	5.3e-07	***
Organic layer depth	Depth	7, 399	33.19	<2e-16	***
pH	pH	7, 399	22.55	<2e-16	***
EC (proxy for salinity)	EC	7, 399	91.10	<2e-16	***
Moisture by volume	M_vol	7, 399	97.02	<2e-16	***
Bulk density	Bul_den	7, 399	212.20	<2e-16	***
LOI550	LOI_550	7, 399	133.80	<2e-16	***
LOI850	LOI_850	7, 399	125.70	<2e-16	***
Peat composition	Peat	7, 399	307.10	<2e-16	***
Sand composition	Sand	7, 399	244.00	<2e-16	***
Loamy-soil composition	L.soil	7, 399	169.10	<2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

Tukey's HSD test results are presented in Table 4.5.

Table 4.5: Soil type means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at p<0.05. Soil type order within each edaphic factor is numerical.

Edaphic factor	Soil type	*n*	Mean ± Std Error	Min	Max	Tukey group
Bare ground (%)	1	36	11.07 ± 2.49	0.0	62.5	bc
	2	45	6.08 ± 1.65	0.0	37.5	c
	3	43	12.51 ± 2.35	0.0	62.5	abc
	4	30	20.07 ± 4.44	0.0	87.5	ab
	5	49	11.52 ± 1.91	0.0	37.5	bc
	6	103	8.84 ± 10.9	0.0	37.5	c
	7	49	20.81 ± 2.40	0.0	62.5	a
	8	52	7.89 ± 1.81	0.0	62.5	c
Organic layer (cm)	1	36	11.92 ± 0.72	2.0	25.0	b
	2	45	25.82 ± 1.31	9.0	42.0	a
	3	43	16.12 ± 1.62	2.0	37.0	b
	4	30	4.03 ± 1.06	0.0	32.0	c
	5	49	13.45 ± 1.01	4.0	45.0	b
	6	103	23.99 ± 1.14	5.0	45.0	a
	7	49	11.98 ± 0.95	2.0	33.0	b
	8	52	25.19 ± 1.38	10.0	40.0	a

Edaphic factor	Soil type	*n*	Mean ± Std Error	Min	Max	Tukey group
pH	1	36	6.33 ± 0.19	4.36	8.36	bcd
	2	45	5.78 ± 0.09	4.45	7.39	e
	3	43	6.51 ± 0.15	4.51	8.05	bc
	4	30	7.38 ± 0.15	5.18	8.17	a
	5	49	6.11 ± 0.11	4.01	7.92	cde
	6	103	6.00 ± 0.05	4.20	8.15	de
	7	49	6.78 ± 0.09	4.83	8.08	b
	8	52	5.78 ± 0.08	3.86	7.25	e
EC (dS/m)	1	36	4.86 ± 0.47	0.80	12.15	f
	2	45	43.02 ± 1.79	20.22	65.90	a
	3	43	15.44 ± 1.35	1.89	45.10	d
	4	30	3.16 ± 0.34	0.40	7.56	f
	5	49	8.94 ± 0.89	0.48	23.32	ef
	6	103	29.35 ± 1.19	2.20	56.03	b
	7	49	13.04 ± 1.23	2.01	57.73	de
	8	52	23.52 ± 1.62	2.48	49.43	c
Moisture by volume (%)	1	36	35.70 ± 2.20	11.34	58.32	c
	2	45	81.65 ± 1.35	56.55	98.50	a
	3	43	68.45 ± 2.37	40.31	94.68	b
	4	30	38.02 ± 2.61	5.54	62.69	c
	5	49	66.27 ± 1.39	33.66	83.89	b
	6	103	79.40 ± 1.15	41.76	98.60	a
	7	49	66.78 ± 1.45	37.46	89.25	b
	8	52	77.39 ± 1.29	58.18	94.60	a
Bulk density (g/cm^3)	1	36	0.82 ± 0.04	0.15	1.43	b
	2	45	0.17 ± 0.00	0.11	0.27	e
	3	43	0.48 ± 0.03	0.26	1.01	d
	4	30	1.22 ± 0.04	0.75	1.56	a
	5	49	0.54 ± 0.03	0.25	1.13	d
	6	103	0.25 ± 0.01	0.08	0.67	e
	7	49	0.69 ± 0.03	0.29	1.15	c
	8	52	0.17 ± 0.01	0.09	0.34	e
LOI550 (%)	1	36	10.68 ± 0.94	2.89	23.65	d
	2	45	46.47 ± 1.20	25.69	66.27	a
	3	43	21.34 ± 1.21	5.76	37.15	c
	4	30	2.59 ± 0.24	0.81	5.56	e
	5	49	21.63 ± 1.43	1.44	50.24	c
	6	103	35.12 ± 1.28	5.59	72.56	b
	7	49	12.07 ± 1.26	3.12	41.86	d
	8	52	51.49 ± 1.78	24.59	78.85	a

Edaphic factor	Soil type	*n*	Mean ± Std Error	Min	Max	Tukey group
LOI850 (%)	1	36	12.85 ± 1.30	3.01	38.24	de
	2	45	51.99 ± 1.18	31.83	69.59	a
	3	43	24.66 ± 1.29	7.11	42.68	c
	4	30	5.82 ± 0.94	1.17	24.14	e
	5	49	23.71 ± 1.48	1.78	52.70	c
	6	103	39.34 ± 1.32	7.55	75.82	b
	7	49	14.96 ± 1.63	3.77	53.62	d
	8	52	54.53 ± 1.79	28.20	80.65	a
Peat composition (%)	1	36	2.50 ± 0.93	0.00	17.50	ef
	2	45	87.50 ± 0.00	87.50	87.50	a
	3	43	17.27 ± 2.47	0.00	62.50	cd
	4	30	0.33 ± 0.23	0.00	5.00	f
	5	49	2.55 ± 0.83	0.00	17.50	ef
	6	103	66.77 ± 1.82	17.50	87.50	b
	7	49	10.66 ± 2.08	0.00	37.50	de
	8	52	21.78 ± 2.47	0.00	62.50	c
Sand composition (%)	1	36	26.04 ± 3.67	0.00	62.50	c
	2	45	0.78 ± 0.27	0.00	5.00	e
	3	43	5.06 ± 1.48	0.00	37.50	de
	4	30	87.50 ± 0.00	87.50	87.50	a
	5	49	11.28 ± 2.07	0.00	62.50	d
	6	103	3.59 ± 0.76	0.00	37.50	e
	7	49	59.64 ± 2.91	17.50	87.50	b
	8	52	2.26 ± 1.06	0.00	37.50	e
Loamy-soil composition (%)	1	36	54.38 ± 4.31	0.00	87.50	b
	2	45	1.67 ± 0.75	0.00	17.50	d
	3	43	18.55 ± 2.10	0.00	37.50	c
	4	30	3.08 ± 0.67	0.00	17.50	d
	5	49	72.70 ± 2.05	37.50	87.50	a
	6	103	7.96 ± 1.02	0.00	37.50	d
	7	49	18.78 ± 2.37	0.00	62.50	c
	8	52	55.67 ± 2.83	17.50	87.50	b

Bare ground – 3 levels of difference: soil types 3, 4 and 7 shared commonality in terms of means (Tukey group **a**); similar for soil types 1, 3, 4 and 5 as all displayed commonality (group **b**), and again, for types 1, 2, 3, 5, 6 and 8 which were not significantly different in terms of means, as they shared a common Tukey group (**c**).

Mean bare ground values varied three-fold, soil type 2 (6.08 ± 1.65) displayed the lowest bare ground cover, while soil type 4 and 7 (20.07 ± 4.44, 20.81 ± 2.40

respectively), were the most barren soil types. The greatest bare ground range was displayed by soil type 4 (0.0-87.5, 87.5), followed by types 1, 3, 7 and 8 (all 0.0-62.5, 62.5). Soil types 2, 5 and 6 had the smallest range of bare ground cover (all 0.0-37.5, 37.5). It was noted that for each soil type, the minimum bare ground value was zero.

Organic layer depth – 3 levels of difference: soil types 2, 6 and 8 displayed similar means (share group **a**); soil types 1, 3, 5 and 7 were similar in terms of means (Tukey group **b**), however, soil type 4 was significantly different to both groupings (lone member of group **c**).

Organic layer means differed six-fold with soil type 4 (4.03 ± 1.06) being the shallowest, whereas types 2 and 8 (25.82 ± 1.31, 25.19 ± 1.38 respectively) displayed the greatest organic layer depth. The largest depth range was displayed by soil type 5 (4.0-45.0, 41.0) followed by type 6 (5.0-45.0, 40.0), while the smallest range was found in type 1 (2.0-25.0, 23.0). Soil type 4 recorded the shallowest minimum organic layer (0.0), while the deepest was observed in soil types 5 and 6 (45.0), followed by soil type 2 (42.0)

pH – 5 levels of difference: soil type 4 was significantly different to all others (lone member of group **a**); soil types 1, 3, and 7 all had similar means and form group **b**; types 1, 3 and 5 displayed similarity in terms of means (Tukey group **c**); soil types 1, 5 and 6 were similar (**d**), while types 2, 5, 6, and 8 had similar means (**e**).

Means of pH varied over one and a half pH units where soil type 8 exhibited 5.78 ± 0.08 and type 4 displayed 7.38 ± 0.15. Differences of pH ranged between soil types and varied approximately one pH unit; soil type 2 ranged 4.45-7.39, 2.94, while soil type 1 varied 4.36-8.36, 4.00. The most acidic soils were found in soil type 8 (minimum pH 3.86), the most alkaline found in type 1 (maximum pH 8.36). All soil types pH ranges included both acidic and alkaline values.

EC – 6 levels of difference: significant differences occurred within this edaphic factor. Soil types 2 (Tukey group **a**), 6 (**b**), and 8 (**c**), were significantly different to all other soil types as well as each being significantly different to each other. Soil types 3 and 7

displayed commonalities in terms of means (group **d**); types 5 and 7 were similar (**e**), while soil types 1, 4 and 5 were similar (**f**).

Variation of EC exceeded 10-fold, soil type 4 (3.16 ± 0.34) to that of soil type 2 (43.02 ± 1.79). The greatest EC range was found in soil type 7 (2.01-57.73, 55.72) closely followed by type 6 (2.20-56.03, 53.83), while the lowest EC range was recorded in type 3 (0.40-7.56, 7.16). The lowest EC values (0.40 to 2.48) were found in all soil types except for type 2, where the minimum observation was 20.22. The highest EC values were recorded in soil type 2 (65.90), followed by type 7 (57.73) and type 6 (56.03), while the lowest maximum EC was recorded in soil type 4 (7.56).

Moisture by volume – 3 levels of difference: soil types 2, 6 and 8 showed similarity in terms of means (group **a**); types 3, 5 and 7 had similar means (Tukey group **b**), while types 1 and 4 displayed no significant difference to each other (**c**).

Moisture by volume observations differed greater than two-fold between soil type 1 (35.70 ± 2.20) and soil type 2 (81.65 ± 1.35). The smallest moisture range was recorded by soil type 8 (58.18-94.60, 36.42), the greatest range observed in type 4 (5.54-62.69, 57.15), with type 6 recording a similar range (41.76-98.60, 56.84). Yet there was an eight-fold difference in the minimum value (5.54 to 41.76) between soil types 4 and 6. The greatest moisture was observed in soil type 6 (98.6), closely followed by type 2 (98.50), the lowest maximum value was recorded in soil type 1 (58.32).

Bulk density – 5 levels of difference: three soil types 4 (**a**), 1 (**b**), and 7 (Tukey group **c**) were significantly different to each other and to soil types 3 and 5, which displayed similar means (group **d**) and types 2, 6 and 8, which as a group were not significantly different to each other (**e**).

There was greater than seven-fold variation in mean bulk density among soil types. Soil type 2 was the lightest in weight, recording 0.17 ± 0.00, whereas soil type 4 was the heaviest, recording 1.22 ± 0.04. The smallest range was observed in type 2 (0.11-0.27, 0.16) whereas the largest range was found in soil type 1 (0.15-1.43, 1.28). The lightest soils were found in type 6 (0.08), closely followed by type 8 (0.09), while the heaviest soils were recorded in type 4 (1.56), followed by type 1 (1.43).

LOI550 – 5 levels of difference: soil types 2 and 8 displayed common means (group **a**); type 6 was a lone member of group **b**, soil types 3 and 5 were not significantly different in terms of means (**c**); types 1 and 7 displayed similarity (Tukey group **d**), while soil type 4 was a single member of group **e**.

LOI550 values ranged 20-fold among soil types, the lowest being type 4 (2.59 ± 0.24), with the highest recorded by type 8 (51.49 ± 1.78). Soil type 4 also displayed the smallest LOI range (0.81-5.56, 4.75), while type 6 recorded the largest range (5.59-72.56, 66.97), followed by type 8 (24.59-78.85, 54.26). Minimum LOI values ranged from 0.81 (soil type 4) to 25.69 (type 2), whereas maximum values ranged 5.56 (type 4) to 78.85 (soil type 8).

LOI850 – 5 levels of difference: a replicate of LOI550 (above), with soil type 1 also a member of Tukey group **e**, thus displayed an association with soil type 4.

Results for LOI550 and LOI850 were as one would have expected. The proportion of inorganic matter to total soil matter is very low in Tasmanian coastal saltmarsh soils, as clear in Figures 4.26 and 4.27 (boxplots).

Peat composition – 6 levels of difference: soil types 2 (Tukey group **a**) and 6 (**b**) were significantly different to each other and to all other Tukey groups; types 3 and 8 were similar in terms of means (group **c**); soil types 3 and 7 displayed similarity (**d**); types 1, 5 and 7 recorded similar means (group **e**), while soil types 4 and 5 were not significantly different to each other (**f**).

There was a high degree of variation in means for peat composition; lowest means were observed in soil type 1 (2.50 ± 0.93) and type 5 (2.55 ± 0.83), while highest means were recorded in soil type 2 (87.50 ± 0.00), followed by type 6 (66.77 ± 1.82). All soil types, apart from 2 and 6, recorded minimum peat values of zero, while the highest maximum observations were in soil types 2 and 6 (87.50). The smallest range of peat values was displayed in soil type 2, where all 45 plots recorded 87.5% peat. The greatest peat range was found in soil types 3 and 8 (both 0.00-62.50, 62.5). Each soil type except for 2 and 6, recorded a minimum value of zero.

Sand composition – 5 levels of difference: soil types 4 (Tukey group **a**), 7 (**b**) and 1 (**c**) and were significantly different to each other and to all other Tukey groups; soil types 3

and 5 displayed similar means (**d**), and types 2, 3, 6 and 8 were not significantly different to each other (group **e**).

Similar to peat composition, there was a high degree of disparity between sand composition means. The lowest means were observed in soil types 2, 8, 6 and 3 (ranging 0.78 ± 0.27 to 5.06 ± 1.48), with the highest means found in soil type 4 (87.5 ± 0.00) followed by type 7 (59.64 ± 2.91). The smallest range of sand composition was recorded in soil type 4 (87.5-87.5, 0.0) with no variation among all thirty plots. The next smallest range was observed in soil type 2 (0.0-5.0, 5.0), while the greatest range was displayed in type 7 (17.5-87.5, 70.0). All soil types except for 4 and 7 displayed a minimum of zero.

Loamy-soil composition – 4 levels of difference: soil type 5 was a sole member of Tukey group **a**, types 1 and 8 displayed similar means (group **b**); soil types 3 and 7 display commonality (**c**), while types 2, 4 and 6 were not significantly different (**d**).

Again, variations between means of loamy-soil composition was high. Highest means were found in soil types 8 (55.67 ± 2.83) and 1 (54.38 ± 4.31), while the lowest means were observed in soil types 2 (1.67 ± 0.75) and 4 (3.08 ± 0.67). The largest range was recorded in soil type 1 (1.0-87.5, 87.5), with the smallest range found in type 2 and 4 (1.0-17.5, 17.5). All soil types except for 5 and 8 displayed minimums of zero, while types 1, 5 and 8 recorded maximum loamy-soil composition of 87.5%.

Summary – soil type groups edaphic factors HSD test

In respect to three edaphic factors, bare ground, organic layer depth, and moisture by volume, commonality is evident between most soil types as these factors only have three levels of difference. However, within EC and peat composition, significant differences are evident between most soil types as these two factors display six levels of difference. Interestingly, soil type 2 is significantly different to all other soil types and Tukey grouping within both factors. Five other factors, pH, bulk density, LOI550 and LOI850, and sand composition display five levels of difference with soil type 4 being significantly different to all other soil types and Tukey groups in three cases. A clear conclusion from these factors, is that soil types 2 and 4 are different to most other soil types. When comparing individual soil types, two types display interesting results:

Soil type 2: low bare ground (~6%), deep organic layer (>25cm), low pH (5.78), high EC (43dS/m), high moisture content (~82%), very low bulk density (<0.2g/cm^3), high LOI (46%), very high peat composition (87%), yet very low sand and loamy-soil composition (<2% and <1% respectively).

Soil type 4: high bare ground (>20%), shallow organic layer (4cm), neutral pH (7.38), low EC (~3dS/m), medium moisture content (~40%), high bulk density (>1.2g/cm^3), low LOI (<3%), very low peat and loamy-soil composition (<1% and ~3% respectively), yet very high sand composition (87%).

This suggested that there may be a degree of correlation between several edaphic factors, 1) low bare ground cover/deep organic layer to high bare ground cover/ shallow organic layer, 2) deep organic depth/high EC and shallow organic depth/low EC, and 3) very low bulk density/very high peat composition and high bulk density/ very low peat composition. However, this is not apparent in correlation tests (see Section 4.3.1).

The ANOVA and Tukey's HSD test results suggest that EC and peat composition are excellent indicators of difference in identifying various coastal saltmarsh soil types, between soil types, followed by LOI, bulk density and sand composition.

4.4.4 Climate variables

Boxplots

Individual soil type groups were aligned to climatic variables of mean annual rainfall, highest and lowest annual rainfall, mean annual maximum and minimum temperatures, highest maximum and lowest minimum annual recorded temperatures, and mean highest and lowest daily solar exposure, and tested using boxplots and ANOVA (Figures 4.31 to 4.39).

Similar figure pairs (e.g. rainfall, temperature), display the same data range to aid better visualisation of results. Observations on boxplots are provided with Table 4.7 – Tukey groups.

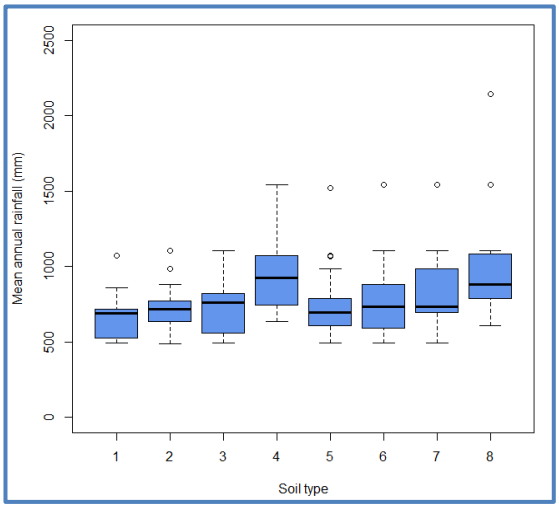


Figure 4.31: Soil type and mean annual rainfall.

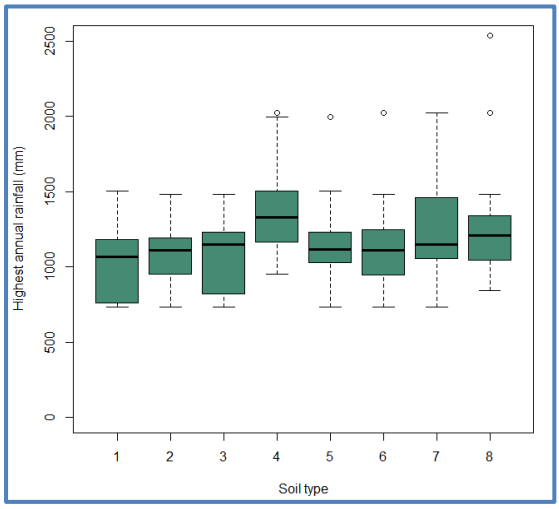


Figure 4.32: Soil type and highest annual rainfall recorded.

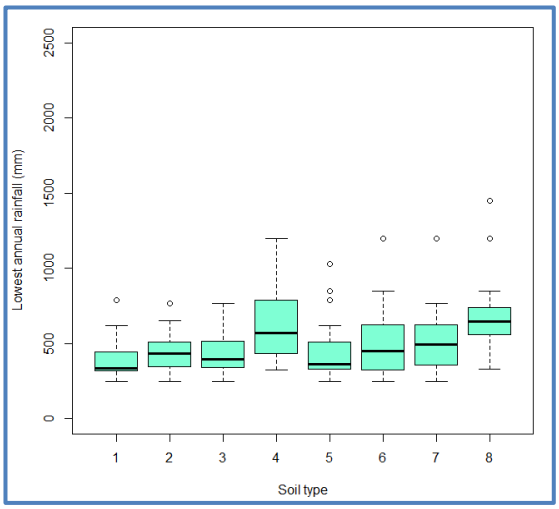


Figure 4.33: Soil type and lowest annual rainfall recorded.

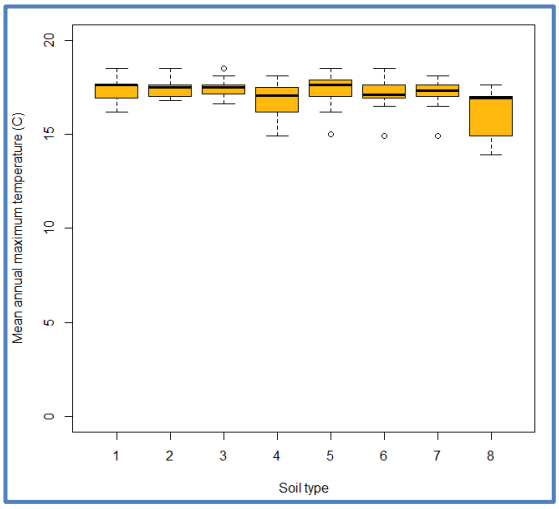


Figure 4.34: Soil type and mean annual maximum temperature.

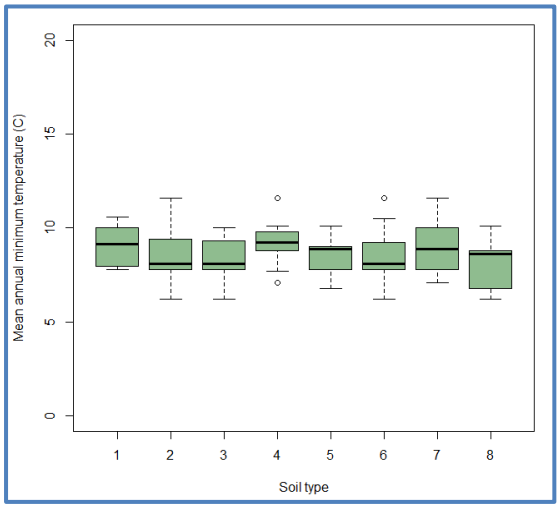


Figure 4.35: Soil type and mean annual minimum temperature.

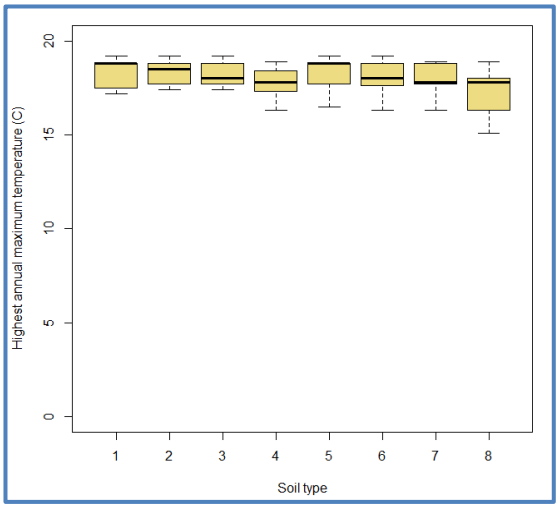


Figure 4.36: Soil type and highest annual maximum temperature.

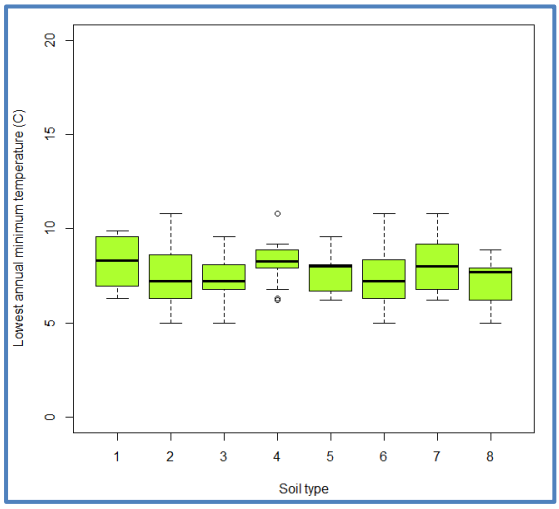


Figure 4.37: Soil type and lowest annual minimum temperature.

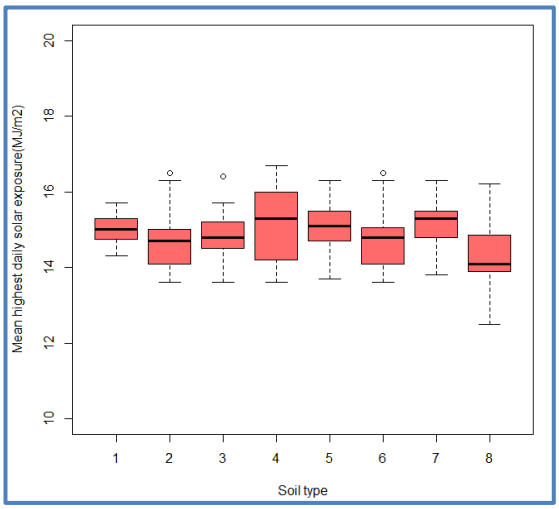


Figure 4.38: Soil type and mean highest daily solar exposure.

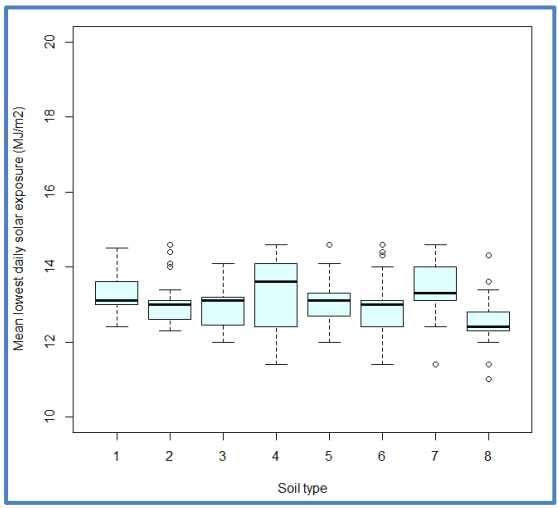


Figure 4.39: Soil type and mean lowest daily solar exposure.

Climate variables ANOVA

The ANOVA outputs of climate variables are presented in Table 4.6.

Table 4.6: ANOVA results for climate variables – sorted by order of boxplots (see Figures 4.31 to 4.39).

Variable	Code	Df	F value	p-value	
Mean annual rainfall	Rain_Mean	7, 399	9.461	7.07e-11	***
Highest annual rainfall recording	Rain_High	7, 399	7.904	5.50e-09	***
Lowest annual rainfall recording	Rain_Low	7, 399	9.813	2.66e-11	***
Mean annual maximum temperature	T_Max_Mean	7, 399	12.780	7.73e-15	***
Mean annual minimum temperature	T_Min_Mean	7, 399	4.428	9.36e-05	***
Highest annual maximum temperature	T_Max_High	7, 399	7.970	4.57e-09	***
Lowest annual minimum temperature	T_Min_Low	7, 399	3.895	4.03e-04	***
Mean Highest daily solar exposure	SR_High	7, 399	9.160	1.63e-10	***
Mean lowest daily solar exposure	SR_Low	7, 399	8.095	3.21e-09	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

All climate variables displayed significant differences ($p<0.001$) between soil types. The low p-value for each indicated that there was at least one soil type within each variable that was significantly different to all other soil types within that same variable.

Tukey's HSD test results are presented in Table 4.7.

Table 4.7: Soil type means, standard error, range (minimum to maximum) and Tukey groups for each climate variable. Within each climate variable, the values followed by the same letter (Tukey groups) are not different at $p<0.05$. Soil type order within each climate variable is numerical.

Climate Variable	Soil type	*n*	Mean ± Std Error	Min	Max	Tukey group
Mean annual rainfall (mm)	1	36	674 ± 29.08	492	1073	c
	2	45	707 ± 22.15	485	1104	c
	3	43	738 ± 26.75	492	1104	c
	4	30	986 ± 55.46	636	1543	ab
	5	49	794 ± 73.47	492	1518	c
	6	103	766 ± 23.32	492	1543	c
	7	49	839 ± 36.43	492	1543	bc
	8	52	1002 ± 53.45	610	2143	a
Highest annual rainfall (mm)	1	36	1032 ± 41.48	735	1504	c
	2	45	1063 ± 30.11	735	1484	c
	3	43	1104 ± 37.70	735	1484	c
	4	30	1426 ± 59.63	952	2024	a
	5	49	1194 ± 49.97	735	1993	bc
	6	103	1106 ± 27.54	735	2024	c
	7	49	1226 ± 43.18	735	2024	abc
	8	52	1322 ± 59.31	844	2538	ab
Lowest annual rainfall (mm)	1	36	406 ± 26.58	247	789	c
	2	45	438 ± 19.48	247	768	c
	3	43	437 ± 20.08	247	768	c
	4	30	643 ± 47.68	322	1196	ab
	5	49	467 ± 34.72	247	1026	c
	6	103	496 ± 22.11	247	1196	c
	7	49	526 ± 33.89	247	1196	bc
	8	52	694 ± 38.35	330	1449	a
Mean annual maximum temperature (°C)	1	36	17.33 ± 0.10	16.2	18.5	a
	2	45	17.43 ± 0.06	16.8	18.5	a
	3	43	17.43 ± 0.07	16.6	18.5	a
	4	30	16.76 ± 0.19	14.9	18.1	bc
	5	49	17.28 ± 0.14	15.0	18.5	ab
	6	103	17.21 ± 0.06	14.9	18.5	ab
	7	49	17.26 ± 0.09	14.9	18.1	ab
	8	52	16.31 ± 0.16	13.9	17.6	c

Climate Variable	Soil type	*n*	Mean ± Std Error	Min	Max	Tukey group
Mean annual minimum temperature (°C)	1	36	9.01 ± 0.19	7.8	10.6	ab
	2	45	8.41 ± 0.18	6.2	11.6	abc
	3	43	8.53 ± 0.16	6.2	10.0	abc
	4	30	9.14 ± 0.17	7.1	11.6	a
	5	49	8.61 ± 0.12	6.8	10.1	abc
	6	103	8.36 ± 0.14	6.2	11.6	bc
	7	49	8.92 ± 0.17	7.1	11.6	ab
	8	52	8.03 ± 0.17	6.2	10.1	c
Highest annual maximum temperature (°C)	1	36	18.23 ± 0.12	17.2	19.2	a
	2	45	18.31 ± 0.09	17.4	19.2	a
	3	43	18.22 ± 0.09	17.4	19.2	a
	4	30	17.77 ± 0.16	16.3	18.9	ab
	5	49	18.29 ± 0.12	16.5	19.2	a
	6	103	18.09 ± 0.06	16.3	19.2	a
	7	49	18.01 ± 0.09	16.3	18.9	a
	8	52	17.41 ± 0.15	15.1	18.9	b
Lowest annual minimum temperature (°C)	1	36	8.09 ± 0.22	6.3	9.9	a
	2	45	7.45 ± 0.22	5.0	10.8	ab
	3	43	7.63 ± 0.19	5.0	9.6	ab
	4	30	8.18 ± 0.17	6.2	10.8	a
	5	49	7.57 ± 0.13	6.2	9.6	ab
	6	103	7.42 ± 0.15	5.0	10.8	ab
	7	49	8.01 ± 0.19	6.2	10.8	a
	8	52	7.05 ± 0.18	5.0	8.9	b
Mean highest daily solar exposure (MJ/m^2)	1	36	15.02 ± 0.07	14.3	15.7	ab
	2	45	14.73 ± 0.09	13.6	16.5	bc
	3	43	14.80 ± 0.10	13.6	16.4	ab
	4	30	15.28 ± 0.18	13.6	16.7	a
	5	49	15.07 ± 0.09	13.7	16.3	ab
	6	103	14.71 ± 0.08	13.6	16.5	bc
	7	49	15.22 ± 0.10	13.8	16.3	a
	8	52	14.31 ± 0.12	12.5	16.2	c
Mean lowest daily solar exposure (MJ/m^2)	1	36	13.28 ± 0.09	12.4	14.5	ab
	2	45	12.98 ± 0.08	12.3	14.6	ab
	3	43	12.93 ± 0.07	12.0	14.1	ab
	4	30	13.33 ± 0.18	11.4	14.6	ab
	5	49	13.02 ± 0.08	12.0	14.6	ab
	6	103	12.92 ± 0.07	11.4	14.6	b
	7	49	13.37 ± 0.11	11.4	14.6	a
	8	52	12.50 ± 0.10	11.0	14.3	c

Mean annual rainfall (3 levels of difference): soil types 4 and 8 displayed similar means (Tukey group **a**); types 4 and 7 were not different in terms of means (group **b**), while soil types 1, 2, 3, 5, 6 and 7 were not significantly different and form group **c**.

Annual rainfall means varied less than two-fold across all soil groups; soil type 1 (674 ± 29.08) to type 8 (1002 ± 53.45), yet their spreads differed three-fold (492-1073, 581; and 610-2143, 1533 respectively). Soil types 1, 2 and 3, exhibited similar spreads (581, 619 and 612 respectively), and types 4, 5, 6 and 7 displayed common spreads (907, 1026, 1051 and 1051 respectively).

Highest annual rainfall (3 levels of difference): soil types 4, 7 and 8 displayed commonalities (group **a**); types 5, 7 and 8 recorded similar means (Tukey group **b**), and soil types 1, 2, 3, 5, 6 and 7 were not significantly different to each other (group **c**).

Means for highest annual rainfall differed less than 0.5-fold between all soil types, 1032 ± 41.48 (type 1) to 1426 ± 59.63 (type 4), while differences between rainfall spreads for soil types 1 and 8 varied two-fold (769 to 1694). Again, as shown for mean annual rainfall, similar rainfall spreads were recorded within same groups of soil types.

Lowest annual rainfall (3 levels of difference): reflected mean annual rainfall except for soil type 7 which was absent from Tukey group **a**, and soil type 4 was included in group **b**.

Lowest annual rainfall showed similarities to mean annual and highest annual rainfall. Differences in means were 0.5-fold, soil type 1 (406 ± 26.58) and type 8 (694 ± 38.35). Ranges/spreads differed two-fold between types 2 and 3 (both 247-789, 521) and soil type 8 (330-1449, 1119). Lowest minimum values (247) were observed in all soil types except for 4 and 8, while the highest maximum was recorded in soil type 8 (1449).

Mean annual maximum temperature (3 levels of difference): like each rainfall variable, soil types 1, 2, 3, 5, 6 and 7, all shared comparable means (group **a**); soil types 4, 5, 6 and 7 were not significantly different (group **b**), while types 4 and 8 were common in terms of means (Tukey group **c**).

Means of mean annual maximum temperature varied more than 1^{o}C; soil type 8 (16.31 ± 0.16) to types 2 and 3 (17.43 ± 0.06). The lowest minimum observed was in

soil type 8 (13.9), while the highest maximum (18.5) was noted in all types except for soil types 4, 7 and 8. The maximum temperature range was recorded in soil type 8 (13.9-17.6, 3.7), closely followed by type 6 (14.9-18.5, 3.6), whereas the minimum temperature range was observed in soil type 2 (16.8-18.5, 1.7).

Mean annual minimum temperature (3 levels of difference): soil types 1, 2, 3, 4, 5 and 7 displayed no significant difference to each other (Tukey group **a**); types 1, 2, 3, 5, 6 and 7 recorded similarity (group **b**), whereas soil types 2, 3, 5, 6 and 8 were also similar to each other (group **c**).

Again, annual minimum temperature means varied more than 1°C; soil type 8 (8.03 ± 0.17) to soil type 4 (9.14 ± 0.17). The smallest minimum temperature range was found in soil type 1 (7.8-10.6, 2.8), while the largest range was observed in soil types 2 and 6 (both 6.2-11.6, 5.4). The lowest mean minimum temperature (6.2) recorded was in soil types 2, 3, 6 and 8, with the highest minimum temperature (11.6) found in types 2, 4, 6 and 7.

Highest annual maximum temperature (2 levels of difference): there was no significant difference between all soil types except for type 8 (group **a**); soil types 4 and 8 displayed similar means (Tukey group **b**).

Means of highest annual maximum temperature differed less than 1°C; soil type 8 (17.41 ± 0.15) to type 2 (18.31 ± 0.09). The largest temperature range was noted in soil type 8 (15.1-18.9, 3.8), whereas the smallest range was observed in types 2 and 3 (both 17.4-19.2, 1.8). The highest temperature (19.2) was in all soil types except for 4, 7 and 8, with the lowest temperature (15.1) in type 8.

Lowest annual minimum temperature (2 levels of difference): similar to mean annual minimum temperatures, soil types 1 to 7 displayed similar means (Tukey group **a**); while types 2, 3, 4, 5, 6 and 8 were similar in terms of means (group **b**).

Means of lowest annual minimum temperature varied slightly more than 1°C, this between soil type 8 (7.05 ± 0.18) and soil type 4 (8.18 ± 0.17). The lowest temperature (5.0) was recorded in soil types 2, 3, 6 and 8, while the highest minimum temperature (10.8) was noted in types 2, 4, 6 and 8. The smallest range was observed in soil type 5 (6.2-9.6, 3.4), with the largest range in soil types 2 and 6 (both 5.0-10.8, 5.8).

Mean highest daily solar exposure (3 levels of difference): soil types 1, 3, 4, 5 and 7 exhibited commonalities in terms of means (group **a**); soil types 1, 2, 3, 5, 6 and 7 were not different (Tukey group **b**), while types 2, 6 and 8 displayed similar means (group **c**).

Highest daily solar means differed less than one megajoule, this observed between soil type 8 (14.31 ± 0.12) and soil type 4 (15.28 ± 0.18). The lowest and highest solar exposure values were recorded in the same soil types (12.5 and 16.7 respectively). The smallest daily solar exposure spread was found in soil type 1 (1.4), the largest spread in type 8 (3.7).

Mean lowest daily solar exposure (3 levels of difference): soil types 1 to 5 and 7 displayed similar means (group **a**); types 1 to 6 were not significantly different (**b**), yet soil type 8 was significantly different to all other soil types (Tukey group **c**).

The means varied less than one megajoule between soil type 8 (12.50 ± 0.10) and soil type 7 (13.37 ± 0.11). The maximum solar exposure values (14.6) were recorded in soil types 2, 4, 5, 6 and 7, while the minimum (11.0) was observed in type 8. The largest daily solar exposure range was found in soil type 8 (11.0-14.3, 3.3), whereas the smallest range exhibited by types 1 and 3 (12.4-14.5, 2.1 and 12.0-14.1, 2.1 respectively).

Summary – soil type group climatic variables HSD test

In respect to rainfall variables (mean annual, highest annual and lowest annual), significant commonality is evident among most soil types, however, types 4 and 7 display variation to other soil type groupings (Tukey groups). This is replicated in mean annual maximum temperature and highest maximum and lowest minimum annual recorded temperatures, where soil types 4 and 8 are different to other soil types, yet the means of the remaining soil types display similarity. The most notable outcome of all Tukey tests on climate variables is noted in lowest mean daily solar exposure, where soil type 8 is significantly different to all other types. A clear interpretation from the Tukey test results, is that in many instances, soil types 4 and 8 are different to most other soil types, this based on two variables, rainfall and temperature.

Summary – soil type group edaphic and climatic attributes

The individual Tukey HSD tests on edaphic factors and climate variables also emphasise another important point. Two of the 11 edaphic factors (EC and peat

composition) record six levels of difference, another five factors (pH, bulk density, LOI550 and 850, and sand composition), display five levels of difference. Yet, of the nine climate variables, seven of them exhibit three levels, while the remainder (annual highest mean maximum temperature and annual lowest mean minimum temperature), display just two levels of difference. This highlights the value of edaphic factors, principally EC and peat composition, in distinguishing differences between soil types, and at the same time suggesting that, especially in this study, the diminishing importance of using climate variables to determine difference between soil types, especially as stand-alone.

4.4.5 Indicator plant species

Herein, the terms "soil type" and "group" are interchangeable and used depending on the context within the text.

Of the 52 plant species identified throughout the vegetation assessments, 19 species (36.5%) were identified as indicator species ($p<0.01$) for the eight soil type groups.

All soil types, except for type 6, had a combination of more than two plant species that can act as indicators (in combination with others) for each soil type, with species dominance determined by increasing p-value followed by decreasing "Stat" value (Table 4.8).

Table 4.8: Indicator plant species ($p<0.01$) for each soil type (group order numerical).
Component A = *positive predictive value;* **Component B** = *sensitivity* – see Chapter 3, section 3.3.5.
Note: species within each soil type are ordered by p-value then by "Stat".

Soil type	Plant species	A	B	IndVal	Stat	p-value	
1	*Austrostipa stipoides*	0.7852	0.3043	0.2389	0.489	0.001	***
	Lawrencia spicata	0.9064	0.1667	0.1511	0.389	0.001	***
	Disphyma crassifolium	0.7895	0.1719	0.1357	0.368	0.001	***
	Distichlis distichophylla	0.7397	0.2087	0.1544	0.393	0.002	**
	Sarcocornia blackiana	0.8514	0.1304	0.1110	0.333	0.003	**
	Poa labillardierei	0.9390	0.0876	0.0822	0.287	0.003	**
	Gahnia filum	0.9412	0.1679	0.1580	0.398	0.006	**
	Plantago coronopus i	0.8597	0.0833	0.0716	0.268	0.006	**
	Ficinia nodosa	0.9442	0.0778	0.0735	0.271	0.019	*
2	*Triglochin stricta*	0.6906	0.0889	0.0614	0.248	0.004	**
	Tecticornia arbuscula	0.8979	0.1869	0.1678	0.410	0.005	**
	Gahnia filum	0.9412	0.1679	0.1580	0.398	0.006	**
	Samolus repens	0.9140	0.0120	0.0110	0.525	0.012	*

Soil type	Plant species	A	B	IndVal	Stat	p-value	
3	*Disphyma crassifolium*	0.7895	0.1719	0.1357	0.368	0.001	***
	Tecticornia arbuscula	0.8979	0.1869	0.1678	0.410	0.005	**
	Gahnia filum	0.9412	0.1679	0.1580	0.398	0.006	**
	Samolus repens	0.9140	0.0120	0.0110	0.525	0.012	*
	Atriplex paludosa	0.5955	0.0930	0.0554	0.235	0.047	*
4	*Austrostipa stipoides*	0.7852	0.3043	0.2389	0.489	0.001	***
	Isolepis cernua	0.9026	0.1450	0.1309	0.362	0.001	***
	Distichlis distichophylla	0.7397	0.2087	0.1544	0.393	0.002	**
	Sarcocornia blackiana	0.8514	0.1304	0.1110	0.333	0.003	**
	Schoenoplectus pungens	1.0000	0.0633	0.0633	0.252	0.008	**
	Samolus repens	0.9140	0.0120	0.0110	0.525	0.012	*
	Ficinia nodosa	0.9442	0.0778	0.0735	0.271	0.019	*
5	*Austrostipa stipoides*	0.7852	0.3043	0.2389	0.489	0.001	***
	Leptinella longipes	0.9181	0.1485	0.1363	0.369	0.001	***
	Disphyma crassifolium	0.7895	0.1719	0.1357	0.368	0.001	***
	Isolepis cernua	0.9026	0.1450	0.1309	0.362	0.001	***
	Distichlis distichophylla	0.7397	0.2087	0.1544	0.393	0.002	**
	Sarcocornia blackiana	0.8514	0.1304	0.1110	0.333	0.003	**
	Poa labillardierei	0.9390	0.0876	0.0822	0.287	0.003	**
	Apodasmia brownii	0.6694	0.1584	0.1060	0.326	0.004	**
	Tecticornia arbuscula	0.8979	0.1869	0.1678	0.410	0.005	**
	Gahnia filum	0.9412	0.1679	0.1580	0.398	0.006	**
	Lilaeopsis polyantha	1.0000	0.0612	0.0612	0.247	0.007	**
	Schoenoplectus pungens	1.0000	0.0633	0.0633	0.252	0.008	**
	Ficinia nodosa	0.9442	0.0778	0.0735	0.271	0.019	*
6	*Tecticornia arbuscula*	0.8979	0.1869	0.1678	0.410	0.005	**
	Samolus repens	0.9140	0.0120	0.0110	0.525	0.012	*
7	*Tecticornia arbuscula*	0.8979	0.1869	0.1678	0.410	0.005	**
	Gahnia filum	0.9412	0.1679	0.1580	0.398	0.006	**
	Samolus repens	0.9140	0.0120	0.0110	0.525	0.012	*
8	*Leptinella longipes*	0.9181	0.1485	0.1363	0.369	0.001	***
	Isolepis cernua	0.9026	0.1450	0.1309	0.362	0.001	***
	Poa labillardierei	0.9390	0.0876	0.0822	0.287	0.003	**
	Apodasmia brownii	0.6694	0.1584	0.1060	0.326	0.004	**
	Gahnia filum	0.9412	0.1679	0.1580	0.398	0.006	**
	Samolus repens	0.9140	0.0120	0.0110	0.525	0.012	*
	Zoysia macrantha	1.0000	0.0577	0.0577	0.240	0.012	*
	Ficinia nodosa	0.9442	0.0778	0.0735	0.271	0.019	*

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. IndVal = Indicator value (see Chapter 3, Section 3.3.5). i = introduced species.

Note: major species – *Sarcocornia quinqueflora, Juncus kraussii* and *Selliera radicans* are absent in the above list, indicating that these three species were present in all soil types, therefore are not "classified" as indicator species.

Species dominance is based on Components A (predictive value) and B (sensitivity value), the Indicator value index is the product of the components. Soil type 6 is dominated by only two species: a) *Tecticornia arbuscula* where it is classed as an good indicator (A = 0.8979), yet the sensitivity value is low (B = 0.1869) signifying that is not expected to be found in all group members, nor is it restricted to this soil type as it is also found in soil types 2, 3, 5 and 7; and b) *Samolus repens,* where again it is classed as an good indicator (A = 0.9140), yet the sensitivity value is low (B = 0.0120), indicating that it is unlikely to be found in all group members nor restricted to this soil type, as it is also found in soil types 2, 3 4, 7 and 8. Both *T. arbuscula* and *S. repens* are common species. Soil type 5 has 13 species listed as indicators, the top billing (highest indicator value of 0.2389) being *Austrostipa stipoides.* This plant species is regarded as a good indicator for this group (A = 0.7852) and has the best B (sensitivity) value (0.3043) in this soil type (and of all 19 species). The B value indicates that the species is not expected to be found in every member of this soil type, nor is it restricted to this soil type, it is also found in two other soil types, types 1 and 4. With no single plant species being restricted to one soil type, and in many cases, many species found across a number of soil types, this demonstrates the adaptability of coastal saltmarsh plants to various edaphic factors and soil types.

4.4.6 Regionalisation types

Individual edaphic factors, bare ground, O layer depth, pH, EC, moisture by volume, bulk density, LOI550 and 850, and soil composition characteristics – peat, sand and loamy-soil – were aligned to IBRA6.1, IMCRA3.3, BOM coastal districts, geographic regions (Edgar *et al.* 1999), and estuarine classifications (Edgar *et al.* 1999) and tested using boxplots and ANOVA.

IBRA6.1

From herein, the use of the term IBRA, implies version 6.1. The number of plots by soil type by IBRA region are presented in Table 4.9. Data in this table is interpreted by column, therefore exhibiting a focus on IBRA regions.

Table 4.9: Number and percentage (%) of plots by soil type by IBRA region. Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each IBRA region.

Focus of table is IBRA regions, therefore data is viewed by column.

	IBRA regions													
Soil type	**FUR**		**KIN**		**TNS**		**TSE**		**TSR**		**TWE**		**Totals**	
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	5	7	**5**	**10**	0	0	**26**	**13**	0	0	0	0	36	9
2	4	6	3	6	0	0	**34**	**18**	4	6	0	0	**45**	**11**
3	5	7	4	8	**2**	**40**	**25**	**13**	**7**	**11**	0	0	**43**	**11**
4	**12**	**17**	**8**	**16**	0	0	2	1	2	3	**6**	**24**	30	7
5	**13**	**18**	3	6	**2**	**40**	**22**	**11**	3	5	**6**	**24**	**49**	**12**
6	**11**	**15**	**6**	**12**	**1**	**20**	**60**	**31**	**21**	**35**	**4**	**16**	**103**	**25**
7	**15**	**22**	**16**	**30**	0	0	13	7	2	3	**3**	**12**	**49**	**12**
8	6	8	**6**	**12**	0	0	11	6	**23**	**37**	**6**	**24**	**52**	**13**
Totals	71	100	51	100	5	100	193	100	62	100	25	100	407	100

Note: the percent column value is the percentage of plots of the total individual IBRA region within soil type, viewed by column. For example, region **TSE** (total 193 plots), **13% of plots are from soil type 1**, **18% from soil type 2**, **13% from soil type 3**, 1% from soil type 4, **11% from soil type 5**, **31% from soil type 6**, 7% from soil type 7, and 6% from soil type 8.

Region codes: **FUR** = Furneaux, **KIN** = King, **TNS** = Tasmanian Northern Slopes, **TSE** = Tasmanian South East, **TSR** = Tasmanian Southern Ranges, **TWE** = Tasmanian West.

Three of the six IBRA regions, FUR, KIN and TSE, contain all soil types. The remaining regions, TNS, TSR and TWE, contain three, six, and five soil types respectively. However, it is acknowledged that two of these regions, TNS and TWE, recorded a low number of sampled plots (1% and 6% respectively), which may suggest why these two regions do not display the full range of soil types. It is also possible that these regions may have a restricted range of soil types due to their position in the landscape.

The IBRA region of dominance within each soil type is presented in Table 4.10. Data in this table is viewed by row, therefore exhibiting a focus on soil type.

Table 4.10: Number and percentage (%) of plots of each soil type present within each IBRA region. Soil type dominance determined within soil type (not within the region). Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each soil type.

Focus of table is soil type, therefore data is viewed by row.

Soil type	IBRA regions												Totals	
	FUR		KIN		TNS		TSE		TSR		TWE			
	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%
1	**5**	**14**	**5**	**14**	0	0	**26**	**72**	0	0	0	0	36	100
2	**4**	**9**	3	7	0	0	**34**	**76**	4	9	0	0	45	100
3	**5**	**12**	4	9	2	5	**25**	**58**	**7**	**16**	0	0	43	100
4	**12**	**40**	**8**	**27**	0	0	2	7	2	7	**6**	**20**	30	100
5	**13**	**27**	3	6	2	4	**22**	**45**	3	6	**6**	**12**	49	100
6	**11**	**11**	6	6	1	1	**60**	**58**	**21**	**20**	4	4	103	100
7	**15**	**31**	**16**	**33**	0	0	**13**	**27**	2	4	3	6	49	100
8	**6**	**12**	**6**	**12**	0	0	**11**	**21**	**23**	**44**	**6**	**12**	52	100
Totals	**71**	**17**	51	13	5	1	**193**	**48**	**62**	**15**	25	6	407	100

Note: the percent column value is the percentage of plots of the total individual soil type within each IBRA region, viewed by row. For example, **soil type 5** (total 49 plots), **27% of plots are in FUR region**, 6% in KIN, 4% in TNS, **45% in TSE**, 6% in TSR and **12% in TWE**.

Region codes: **FUR** = Furneaux (subregion 01, **KIN** = King, **TNS** = Tasmanian Northern Slopes, **TSE** = Tasmanian South East, **TSR** = Tasmanian Southern Ranges, **TWE** = Tasmanian West.

In many cases, soil types are spread among the IBRA regions. Exceptions are soil type 1 which is not present in TNS, TSR and TWE; soil type 2 absent in TNS and TWE, and types 7 and 8 not present in TNS. The low number of plots in TNS is reflective of there being only two sites (five plots) located in this region.

Soil type dominance (data in **blue**) is mostly restricted to individual regions, the exception being soil type 7, where it is dominant in and across two regions, FUR and KIN. Generally, the greatest instance of soil types is within the TSE region (five soil types display dominance, followed by two other types with a secondary dominance – values in **red**). This is followed by the FUR region where two soil types display dominance, two as secondary dominance, and three less dominant. The two regions adjoin and represent the entire east coast of Tasmania including Flinders, Maria and Bruny Islands. It is understood that these results may be somewhat skewed as of the 407 plots sampled, 264 (65%) are in these two regions (FUR and TSE).

Individual edaphic factors were aligned to individual IBRA regions and tested using boxplots and ANOVA.

IBRA regions edaphic factors boxplots

Similar figure pairs display the same data range to aid better visualisation of results.

Commentary on Figures 4.40 to 4.50 are provided with Table 4.12 – Tukey groups.

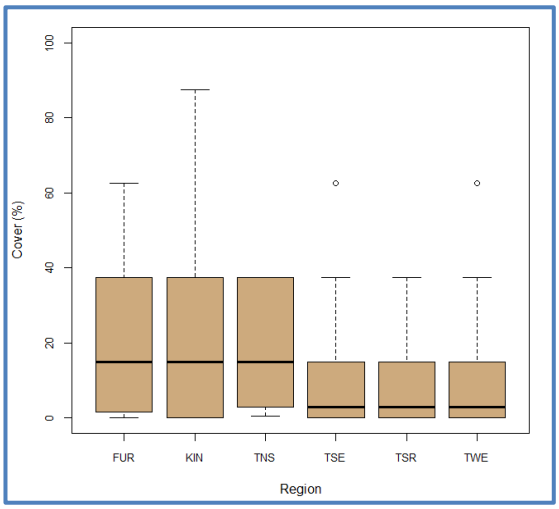


Figure 4.40: IBRA regions and bare ground.

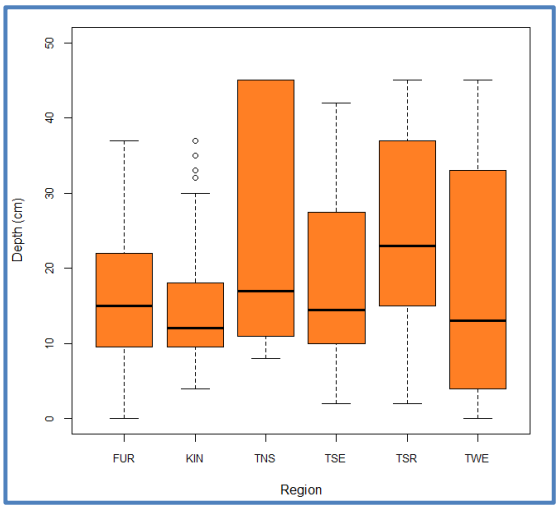


Figure 4.41: IBRA regions and organic layer depth.

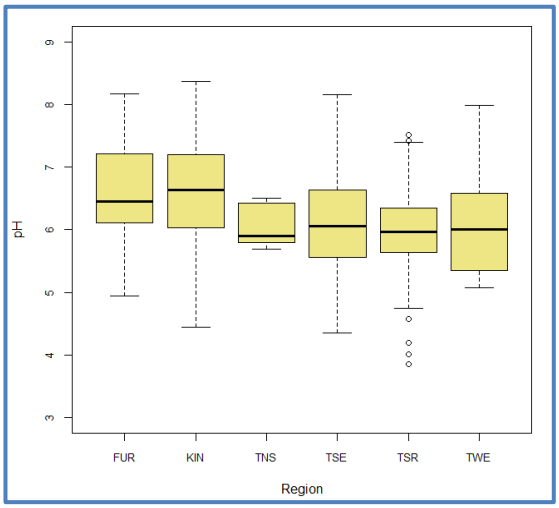


Figure 4.42: IBRA regions and pH.

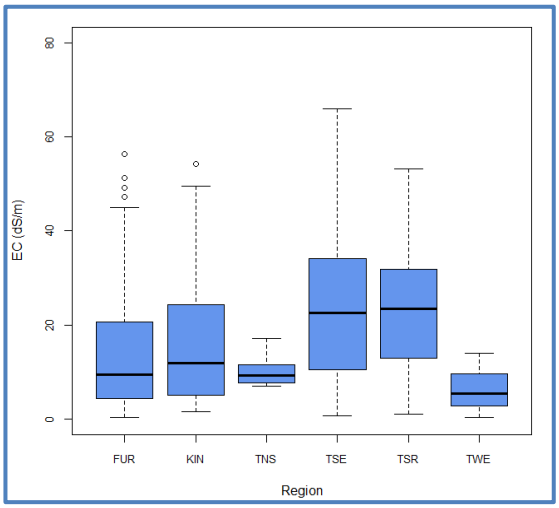


Figure 4.43: IBRA regions and EC.

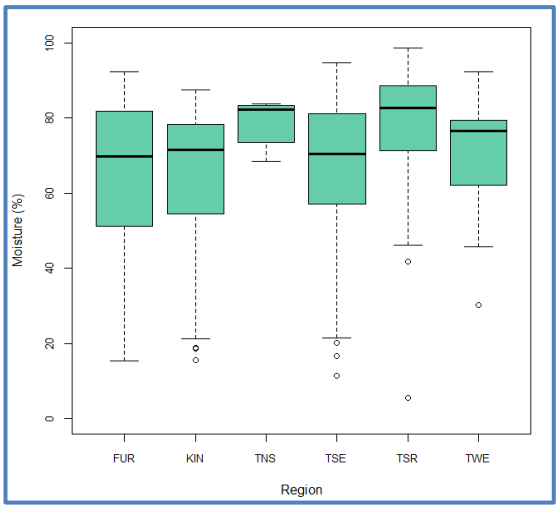


Figure 4.44: IBRA regions and moisture by volume.

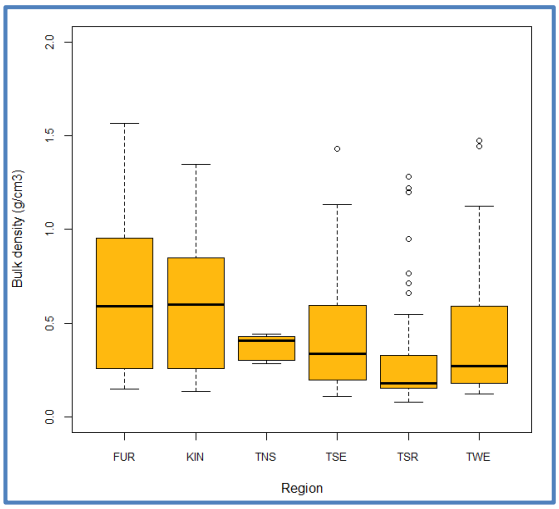


Figure 4.45: IBRA regions and bulk density.

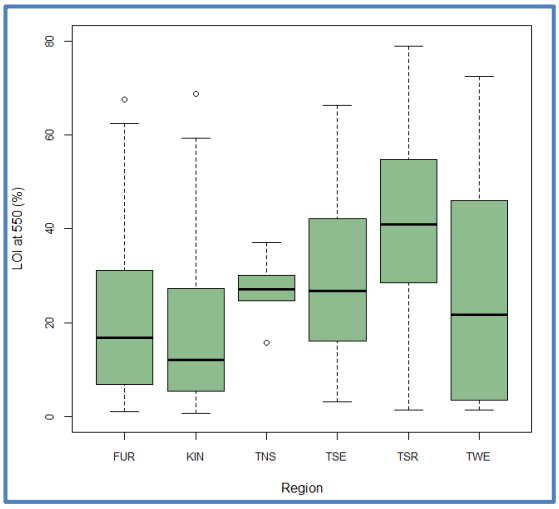


Figure 4.46: IBRA regions and LOI550.

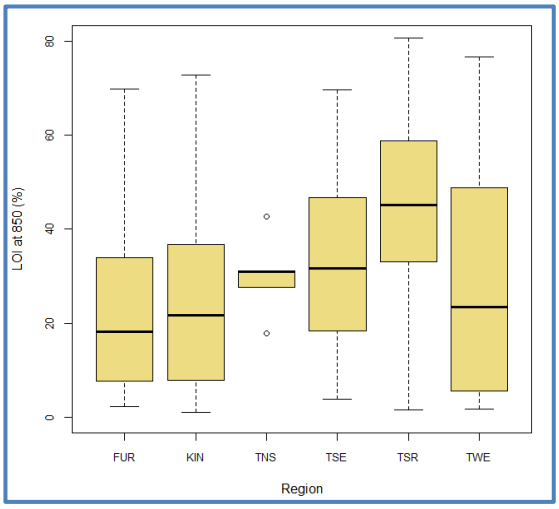


Figure 4.47: IBRA regions and LOI850.

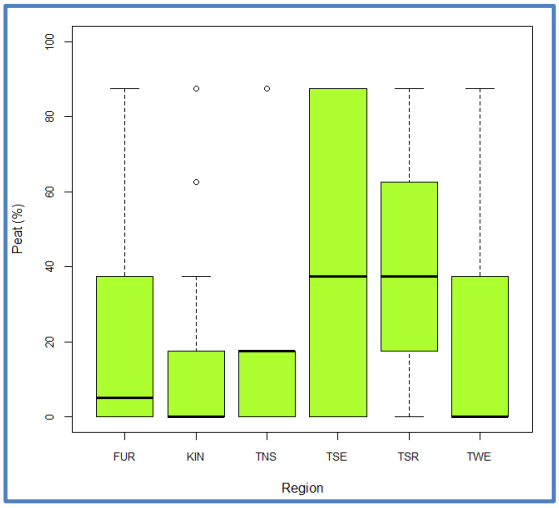


Figure 4.48: IBRA regions and peat composition.

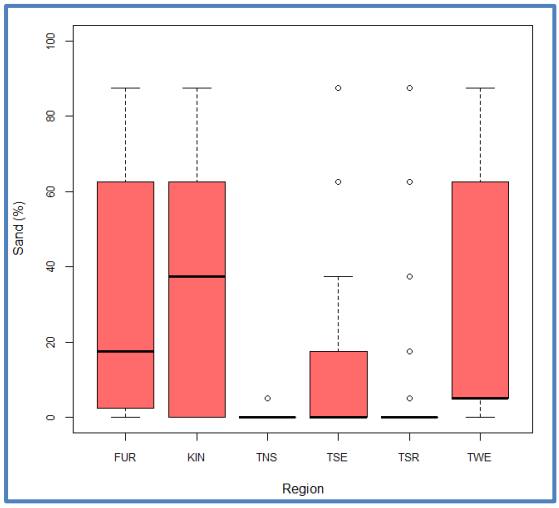


Figure 4.49: IBRA regions and sand composition.

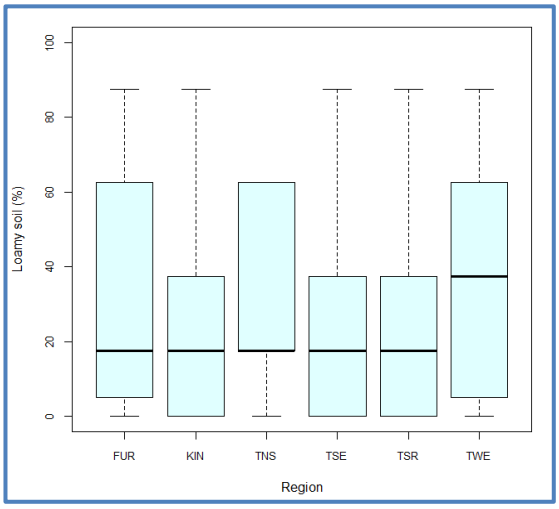


Figure 4.50: IBRA regions and loamy-soil composition.

Region codes: **FUR** = Furneaux (subregion 01),
KIN = King,
TNS = Tasmanian Northern Slopes,
TSE = Tasmanian South East,
TSR = Tasmanian Southern Ranges,
TWE = Tasmanian West.

IBRA regions edaphic factors ANOVA

The ANOVA outputs of edaphic factors aligned to IBRA regions are presented in Table 4.11.

Table 4.11: ANOVA results for soil type edaphic factors aligned to IBRA regions – sorted by order of boxplots.

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	5, 401	7.226	1.71e-06	***
Organic layer depth	Depth	5, 401	7.431	1.11e-06	***
pH	pH	5, 401	7.429	1.11e-06	***
EC (proxy for salinity)	EC	5, 401	11.820	1.12e-10	***
Moisture by volume	M_vol	5, 401	5.284	1.03e-04	***
Bulk density	Bul_den	5, 401	10.390	2.20e-09	***
LOI550	LOI_550	5, 401	13.340	4.91e-12	***
LOI850	LOI_850	5, 401	12.360	3.36e-11	***
Peat composition	Peat	5, 401	7.324	1.39e-06	***
Sand composition	Sand	5, 401	20.670	<2.00e-16	***
Loamy-soil composition	L.soil	5, 401	1.580	1.65e-01	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

All edaphic factors except for loamy-soil composition have significant differences between IBRA regions. The low p-value ($p<0.001$) for each indicates that there is at least one region within each edaphic factor that is significantly different to all other IBRA regions within that factor, while there are no significant differences between soil types in relation to loamy-soil composition.

Tukey's HSD test results are presented in Table 4.12.

Table 4.12: IBRA region means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at $p<0.05$. IBRA region order within each edaphic factor is alphabetical.

Region codes: **FUR** = Furneaux (sub region 01, **KIN** = King, **TNS** = Tasmanian Northern Slopes, **TSE** = Tasmanian South East, **TSR** = Tasmanian Southern Ranges, **TWE** = Tasmanian West.

Edaphic factor	IBRA region	*n*	Mean ± Std error	Min	Max	Tukey group
Bare ground (%)	FUR	71	16.23 ± 1.93	0.00	62.50	a
	KIN	51	18.35 ± 2.76	0.00	87.50	a
	TNS	5	18.70 ± 8.06	0.50	37.50	a
	TSE	193	9.36 ± 0.93	0.00	62.50	ab
	TSR	62	5.60 ± 0.94	0.00	37.50	ab
	TWE	25	15.36 ± 4.32	0.00	62.50	ab

Edaphic factor	IBRA region	*n*	Mean ± Std error	Min	Max	Tukey group
Organic layer (cm)	FUR	71	15.73 ± 1.24	0.00	37.00	ab
	KIN	51	14.53 ± 1.19	4.00	37.00	ab
	TNS	5	25.20 ± 8.21	8.00	45.00	a
	TSE	193	17.81 ± 0.74	2.00	42.00	ab
	TSR	62	25.14 ± 1.54	2.00	45.00	a
	TWE	25	17.80 ± 3.10	0.00	45.00	ab
pH	FUR	71	6.60 ± 0.10	4.94	8.17	a
	KIN	51	6.61 ± 0.12	4.45	8.36	a
	TNS	5	6.06 ± 0.17	5.69	6.50	b
	TSE	193	6.12 ± 0.15	4.36	8.15	b
	TSR	62	5.95 ± 0.09	3.86	7.51	b
	TWE	25	6.17 ± 0.18	5.07	7.99	ab
EC (dS/m)	FUR	71	14.39 ± 0.64	0.40	56.29	cd
	KIN	51	16.32 ± 1.95	1.65	54.15	bc
	TNS	5	10.58 ± 1.83	7.03	17.21	cd
	TSE	193	24.30 ± 0.17	0.80	65.90	a
	TSR	62	23.29 ± 0.64	1.10	53.17	ab
	TWE	25	6.11 ± 0.84	0.48	14.07	d
Moisture by volume (%)	FUR	71	65.54 ± 2.34	15.29	92.19	ab
	KIN	51	62.92 ± 3.03	15.60	87.44	ab
	TNS	5	78.20 ± 3.06	68.44	83.67	a
	TSE	193	66.92 ± 1.28	11.34	94.71	ab
	TSR	62	78.07 ± 2.11	5.54	98.60	a
	TWE	25	69.84 ± 3.50	30.23	92.35	ab
Bulk density (g/cm^3)	FUR	71	0.65 ± 0.05	0.15	1.56	a
	KIN	51	0.59 ± 0.05	0.14	1.35	a
	TNS	5	0.37 ± 0.03	0.28	0.44	b
	TSE	193	0.42 ± 0.02	0.11	1.43	b
	TSR	62	0.29 ± 0.03	0.08	1.28	b
	TWE	25	0.48 ± 0.09	0.12	1.47	ab
LOI550 (%)	FUR	71	20.64 ± 2.05	1.15	67.45	c
	KIN	51	18.52 ± 2.35	0.81	68.77	c
	TNS	5	26.98 ± 3.48	15.84	37.15	bc
	TSE	193	29.18 ± 1.12	3.18	66.27	b
	TSR	62	41.07 ± 2.34	1.36	78.85	a
	TWE	25	27.30 ± 4.87	1.44	72.41	bc

Edaphic factor	IBRA region	*n*	Mean ± Std error	Min	Max	Tukey group
LOI850 (%)	FUR	71	22.98 ± 2.12	2.30	69.72	c
	KIN	51	23.56 ± 2.52	1.17	72.79	c
	TNS	5	30.07 ± 3.98	17.84	42.68	bc
	TSE	193	32.67 ± 1.22	3.97	69.59	b
	TSR	62	44.91 ± 2.42	1.56	80.65	a
	TWE	25	29.39 ± 4.89	1.78	76.55	bc
Peat composition (%)	FUR	71	22.96 ± 03.92	0.00	87.50	bc
	KIN	51	16.81 ± 04.04	0.00	87.50	c
	TNS	5	24.50 ± 16.23	0.00	87.50	abc
	TSE	193	41.38 ± 02.56	0.00	87.50	a
	TSR	62	37.82 ± 03.50	0.00	87.50	ab
	TWE	25	20.00 ± 06.61	0.00	87.50	bc
Sand composition (%)	FUR	71	34.26 ± 3.95	0.00	87.50	a
	KIN	51	41.86 ± 4.92	0.00	87.50	a
	TNS	5	1.00 ± 1.00	0.00	5.00	b
	TSE	193	9.86 ± 1.42	0.00	87.50	b
	TSR	62	8.49 ± 2.89	0.00	87.50	b
	TWE	25	31.10 ± 7.24	0.00	87.50	a
Loamy-soil composition (%)	FUR	71	30.46 ± 03.43	0.00	87.50	a
	KIN	51	22.11 ± 03.25	0.00	87.50	a
	TNS	5	32.00 ± 12.85	0.00	62.50	a
	TSE	193	26.67 ± 02.19	0.00	87.50	a
	TSR	62	24.60 ± 03.41	0.00	87.50	a
	TWE	25	40.00 ± 07.34	0.00	87.50	a

Bare ground – 2 levels of difference: all IBRA regions were not significantly different in terms of means, as they all were in Tukey group **a**; regions TSE, TSR and TWE form group **b**, and were significantly different to the remainder as a group.

Organic layer depth – 2 levels of difference: similar to bare ground, all regions were not significantly different as appear in group **a**; regions FUR, KIN, TSE and TWE were not dissimilar (Tukey group **b**).

pH – 2 levels of difference: regions FUR, KIN and TWE exhibited similar means (Tukey group **a**), but were significantly different to TNS, TSE, TSR and TWE (group **b**) as a group.

EC – 4 levels of difference: significant differences occurred within this edaphic factor: regions TSE and TSR were similar in terms of means (Tukey group **a**); KIN and TSR

display commonality (group **b**); FUR, KIN and TNS had similar means (group **c**), while three regions, FUR, TNS and TWE were similar (group **d**).

Moisture by volume – 2 levels of difference: as a group, all regions were similar (Tukey group **a**), whereas regions FUR, KIN, TSE and TWE were similar (group **b**).

Bulk density – 2 levels of difference: this factor reflected pH.

LOI550 – 3 levels of difference: region TSR was a sole group member (Tukey group **a**); TNS, TSE and TWE displayed similar means (group **b**), and FUR, KIN, TNS and TWE, shared commonality (group **c**).

LOI850 – 3 levels of difference: identical to LOI550 (above).

Peat composition – 3 levels of difference: regions TSE and TSR (Tukey group **a**) in terms of means were significantly different to all other regions; regions FUR, TNS TSR and TWE were similar (group **b**), while FUR, KIN, TNS and TWE displayed similar means (group **c**).

Sand composition – 2 levels of difference: regions FUR, KIN and TWE were similar in terms of means (group **a**); regions TNS, TSE and TSR shared similarity (group **b**).

Loamy-soil composition – 0 level of difference: all regions exhibited similar means (Tukey group **a**), none being significantly different to any other.

Summary – IBRA regions HSD test

Edaphic factor EC displays the greatest level of difference with four levels, both LOI treatments and peat composition exhibit three levels of difference, while the remaining seven edaphic factors display difference levels between zero and two. This result suggests that within the context of IBRA regionalisation, EC could possibly be a reasonable indicator of difference between regions, followed by LOI and the level of peat composition in the sample.

IMCRA3.3

From herein, the use of the term IMCRA, implies version 3.3. The number of plots by soil type by IMCRA region are presented in Table 4.13. Data in this table is interpreted by column, therefore a focus on IMCRA regions.

Table 4.13: Number and percentage (%) of plots by soil type by IMCRA region. Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each IMCRA region.

Focus of table is IMCRA regions, therefore data is viewed by column.

	IMCRA regions															
Soil type	**BGS**		**BRU**		**DAV**		**FLI**		**FRA**		**FRE**		**OTW**		**Totals**	
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	4	6	11	7	0	0	**1**	**11**	**4**	**14**	**15**	**13**	1	7	36	9
2	4	6	**27**	**17**	0	0	**2**	**22**	0	0	11	9	1	7	**45**	**11**
3	**6**	**10**	**25**	**16**	0	0	**1**	**11**	0	0	11	9	0	0	**43**	**11**
4	**9**	**15**	3	2	0	0	**4**	**45**	**9**	**31**	3	3	**2**	**14**	30	7
5	3	5	9	6	1	6	**1**	**11**	**7**	**24**	**27**	**23**	1	7	**49**	**12**
6	**11**	**18**	**43**	**27**	**10**	**59**	0	0	**4**	**14**	**32**	**28**	**3**	**21**	**103**	**25**
7	**18**	**29**	10	6	0	0	0	0	3	10	**12**	**10**	**6**	**44**	**49**	**12**
8	**7**	**11**	**31**	**19**	**6**	**35**	0	0	2	7	6	5	0	0	**52**	**13**
Totals	62	100	159	100	17	100	9	100	29	100	117	100	14	100	407	100

Note: the percent column value is the percentage of plots of the total individual IMCRA region within soil type, viewed by column. For example, region **FRE** (total 117 plots), **13% of plots are from soil type 1**, 9% from soil type 2, 9% from soil type 3, 3% from soil type 4, **23% from soil type 5**, **27% from soil type 6**, **10% from soil type 7**, and 5% from soil type 8.

Region codes: **BGS** = Boags, **BRU** = Bruny, **DAV** = Davey, **FLI** = Flinders, **FRA** = Franklin, **FRE** = Freycinet, **OTW** = Otway.

Three of the seven IMCRA regions, BGS, BRU, and FRE, contain all eight soil types. The remaining regions, DAV, FLI, FRA and OTW, contain three, five, six and six soil types respectively. However, two of these regions, DAV and OTW, record just 4 and 3 percent of the total number of plots, which may be a reason why these regions display a low diversity of soil types. Yet, it is also possible that they may have a restricted range of soil types due to their position in the landscape.

The IMCRA region of dominance of each soil type is presented in Table 4.14. Data in this table is viewed by row, therefore exhibiting a focus on soil type.

Table 4.14: Number and percentage (%) of plots of each soil type present within each IMCRA region. Soil type dominance determined within soil type (not within the region). Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each soil type.

Focus of table is soil type, therefore data is viewed by row.

Soil type	IMCRA regions														Totals	
	BGS		BRU		DAV		FLI		FRA		FRE		OTW			
	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%
1	**4**	**11**	**11**	**31**	0	0	1	3	**4**	**11**	**15**	**42**	1	3	36	100
2	4	9	**27**	**60**	0	0	2	4	0	0	**11**	**24**	1	2	45	100
3	**6**	**14**	**25**	**58**	0	0	1	2	0	0	**11**	**26**	0	0	43	100
4	**9**	**30**	3	10	0	0	**4**	**13**	**9**	**30**	3	10	2	7	30	100
5	3	6	**9**	**18**	1	2	1	2	**7**	**14**	**27**	**55**	1	2	49	100
6	**11**	**11**	**43**	**42**	**10**	**10**	0	0	4	4	**32**	**31**	3	3	103	100
7	**18**	**37**	**10**	**20**	0	0	0	0	3	6	**12**	**24**	**6**	**12**	49	100
8	**7**	**13**	**31**	**60**	**6**	**12**	0	0	2	4	**6**	**12**	0	0	52	100
Totals	**62**	**15**	**159**	**40**	17	4	9	2	29	7	**117**	**29**	14	3	407	100

Note: the percent column value is the percentage of plots of the total individual soil type within each IMCRA region, viewed by row. For example, **soil type 5** (total 49 plots), 6% of plots are in BGS region, **18% in BRU**, 2% in DAV, 2% in FLI, **14% in FRA**, **55% in FRE** and 2% in OTW.

Region codes: **BGS** = Boags, **BRU** = Bruny, **DAV** = Davey, **FLI** = Flinders, **FRA** = Franklin, **FRE** = Freycinet, **OTW** = Otway.

In most cases, individual soil types are not spread across all seven IMCRA regions, the exception being soil type 5, which is present in all regions, though is somewhat limited to one plot in each of DAV, FLI and OTW regions. The most restricted soil type is 3, which is not present in regions DAV, FRA and OTW, and has a very limited presence in region FLI, being present in just one plot.

Soil type dominance (values in **blue**) is mostly restricted to individual regions, the exception being soil type 4, where it is dominant in across two regions, BGS and FRA. Generally, the greatest instance of soil types is within the BRU region (four soil types display dominance, followed by three other types with a secondary dominance – values in **red**). This is followed by the BGS and FRE regions where two soil types display dominance, and where four types also display secondary dominance in the FRE region. The three regions (BGS, BRU and FRE) adjoin and represent the entire northern and eastern coasts of Tasmania including Flinders, Maria and Bruny Islands. It is understood that these results may be somewhat skewed as of the 407 plots sampled, 338 (83%) are in these three regions.

Individual edaphic factors were aligned to IMCRA regions and tested using boxplots and ANOVA.

IMCRA regions edaphic factors boxplots

Similar figure pairs, for LOI, display the same data range to aid better visualisation of results. Observations on Figures 4.51 to 4.61 are provided with Table 4.16 – Tukey groups.

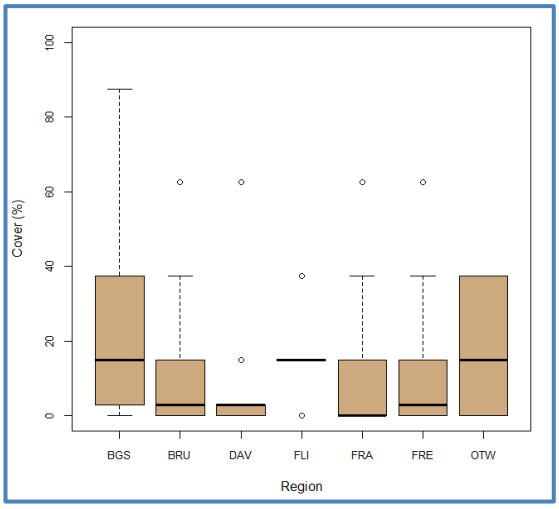


Figure 4.51: IMCRA regions and bare ground.

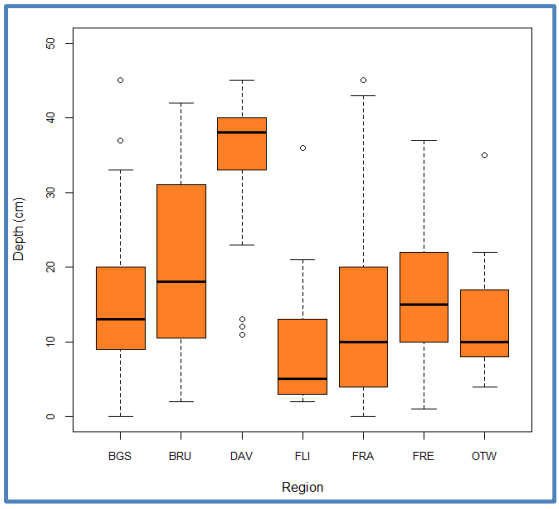


Figure 4.52: IMCRA regions and organic layer depth.

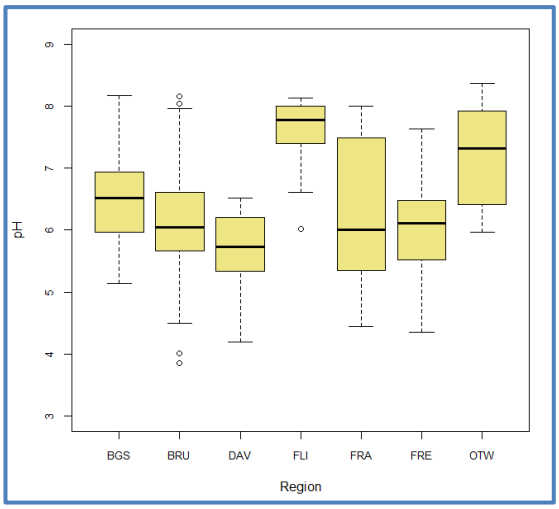


Figure 4.53: IMCRA regions and pH.

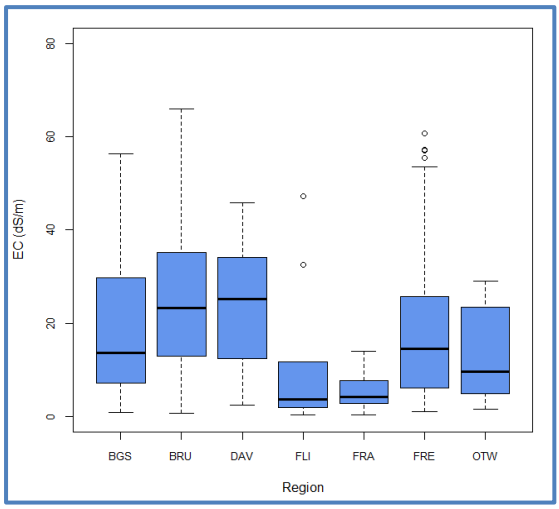


Figure 4.54: IMCRA regions and EC.

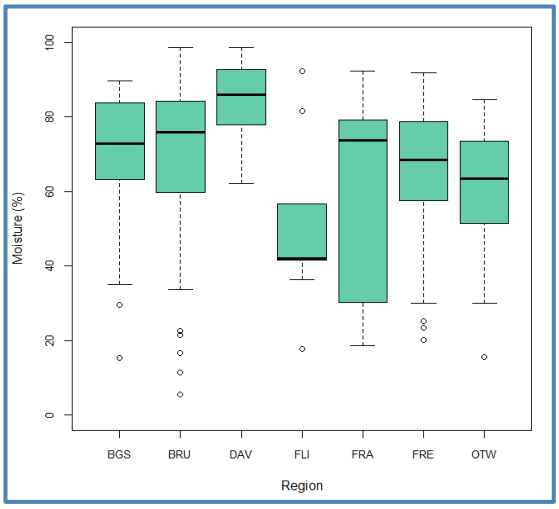


Figure 4.55: IMCRA regions and moisture by volume.

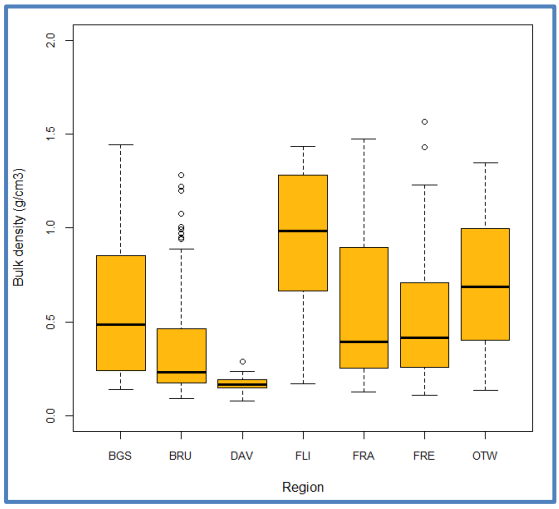


Figure 4.56: IMCRA regions and bulk density.

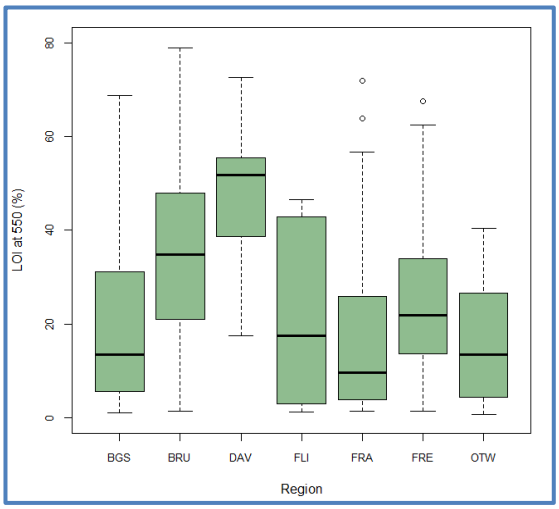


Figure 4.57: IMCRA regions and LOI550.

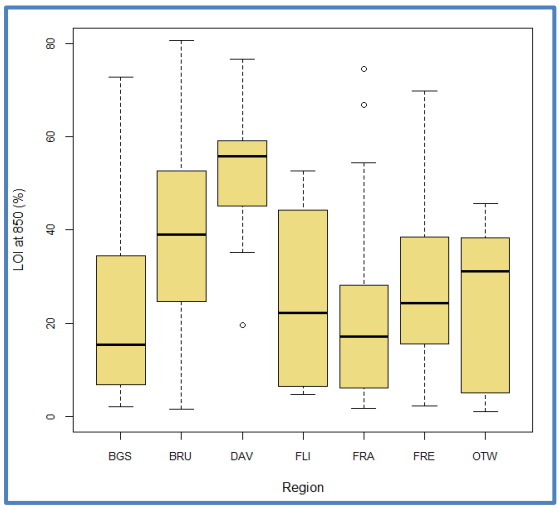


Figure 4.58: IMCRA regions and LOI850.

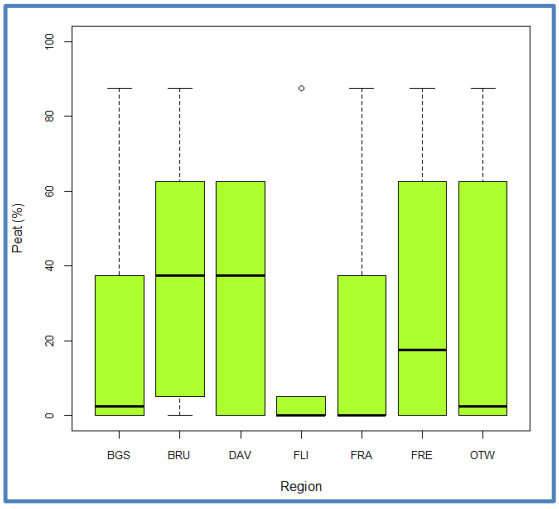


Figure 4.59: IMCRA regions and peat composition.

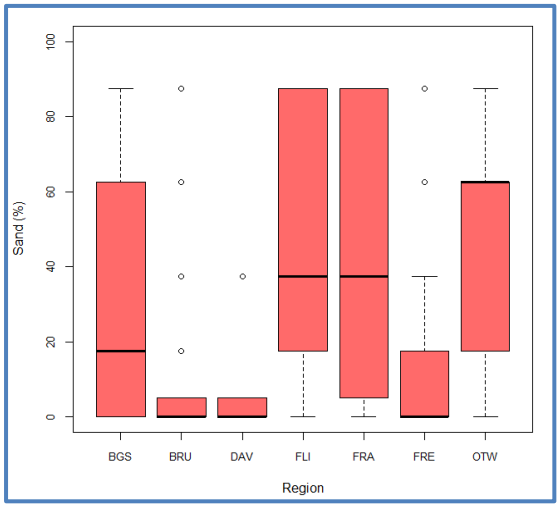
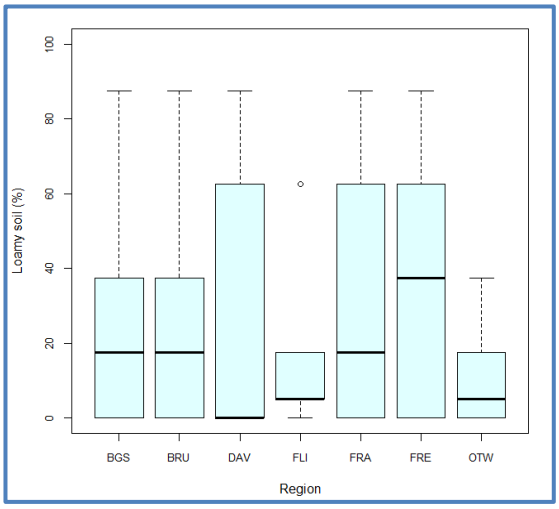


Figure 4.60: IMCRA regions and sand composition.



Region codes: **BGS** = Boags, **BRU** = Bruny, **DAV** = Davey, **FLI** = Flinders, **FRA** = Franklin, **FRE** = Freycinet, **OTW** = Otway.

Figure 4.61: IMCRA regions and loamy-soil composition.

IMCRA regions edaphic factors ANOVA

The ANOVA outputs of edaphic factors aligned to IMCRA regions are presented in Table 4.15.

Table 4.15: ANOVA results for soil type edaphic factors aligned to IMCRA regions – sorted by order of boxplots.

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	6, 400	7.387	1.65e-07	***
Organic layer depth	Depth	6, 400	9.514	8.78e-10	***
pH	pH	6, 400	11.870	2.90e-12	***
EC (proxy for salinity)	EC	6, 400	9.342	1.34e-09	***
Moisture by volume	M_vol	6, 400	6.811	6.83e-07	***
Bulk density	Bul_den	6, 400	12.800	3.06e-13	***
LOI550	LOI_550	6, 400	14.520	5.26e-15	***
LOI850	LOI_850	6, 400	13.800	2.83e-14	***
Peat composition	Peat	6, 400	3.337	3.22e-03	**
Sand composition	Sand	6, 400	16.600	<2.00e-16	***
Loamy-soil composition	L.soil	6, 400	4.178	4.35e-04	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

Each individual edaphic factor has significant differences between IMCRA regions. The low p-value ($p<0.001$) for all, except peat composition, indicates that there is at least one region within each edaphic factor that is significantly different to all other IMCRA regions within that factor.

Tukey's HSD test results are presented in Table 4.16.

Table 4.16: IMCRA region means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at p<0.05. Region order within each edaphic factor is alphabetical.

Region codes: **BGS** = Boags, **BRU** = Bruny, **DAV** = Davey, **FLI** = Flinders, **FRA** = Franklin, **FRE** = Freycinet, **OTW** = Otway.

Edaphic factor	IMCRA region	*n*	Mean ± Std error	Min	Max	Tukey group
Bare ground (%)	BGS	62	21.90 ± 2.40	0.00	87.50	a
	BRU	159	8.58 ± 0.96	0.00	62.50	b
	DAV	17	7.74 ± 3.66	0.00	62.50	b
	FLI	9	16.67 ± 4.47	0.00	37.50	ab
	FRA	29	11.81 ± 3.43	0.00	62.50	b
	FRE	117	9.74 ± 1.22	0.00	62.50	b
	OTW	14	16.61 ± 4.60	0.00	37.50	ab
Organic layer (cm)	BGS	62	15.74 ± 1.37	0.00	45.00	b
	BRU	159	20.21 ± 0.89	2.00	42.00	b
	DAV	17	33.71 ± 2.81	11.00	45.00	a
	FLI	9	10.67 ± 3.80	2.00	36.00	b
	FRA	29	14.72 ± 2.61	0.00	45.00	b
	FRE	117	16.73 ± 0.83	1.00	37.00	b
	OTW	14	13.50 ± 2.19	4.00	35.00	b
pH	BGS	62	6.54 ± 0.09	5.14	8.17	bc
	BRU	159	6.17 ± 0.07	3.86	8.15	d
	DAV	17	5.69 ± 0.15	4.20	6.52	d
	FLI	9	7.50 ± 0.24	6.02	8.13	a
	FRA	29	6.29 ± 0.21	4.45	8.00	cd
	FRE	117	6.03 ± 0.06	4.36	7.63	d
	OTW	14	7.21 ± 0.20	5.96	8.36	ab
EC (dS/m)	BGS	62	19.35 ± 1.98	0.99	56.29	ab
	BRU	159	24.94 ± 1.23	0.80	65.90	a
	DAV	17	24.50 ± 3.39	2.48	45.85	ab
	FLI	9	12.28 ± 5.53	0.40	47.30	bc
	FRA	29	5.53 ± 0.72	0.48	14.07	c
	FRE	117	18.47 ± 1.36	1.16	60.70	b
	OTW	14	13.02 ± 2.75	1.65	29.06	bc
Moisture by volume (%)	BGS	62	69.26 ± 2.40	15.29	89.65	bc
	BRU	159	71.14 ± 1.43	5.54	98.50	ab
	DAV	17	84.52 ± 2.82	62.03	98.60	a
	FLI	9	50.82 ± 7.67	17.82	92.19	c
	FRA	29	58.40 ± 4.84	18.61	92.35	c
	FRE	117	66.35 ± 1.51	20.20	91.85	bc
	OTW	14	57.75 ± 5.27	15.60	84.58	c

Edaphic factor	IMCRA region	*n*	Mean ± Std error	Min	Max	Tukey group
Bulk density (g/cm^3)	BGS	62	0.59 ± 0.05	0.14	1.44	ab
	BRU	159	0.35 ± 0.02	0.09	1.28	c
	DAV	17	0.17 ± 0.01	0.08	0.29	c
	FLI	9	0.90 ± 0.16	0.17	1.43	a
	FRA	29	0.58 ± 0.07	0.13	1.47	ab
	FRE	117	0.51 ± 0.03	0.11	1.56	b
	OTW	14	0.70 ± 0.10	0.14	1.35	ab
LOI550 (%)	BGS	62	19.67 ± 2.16	1.15	68.77	c
	BRU	159	34.39 ± 1.39	1.36	78.85	b
	DAV	17	49.09 ± 3.54	17.47	72.56	a
	FLI	9	20.19 ± 6.67	1.26	46.58	c
	FRA	29	19.08 ± 3.75	1.44	71.88	c
	FRE	117	25.20 ± 1.38	1.53	67.45	c
	OTW	14	15.19 ± 3.27	0.81	40.35	c
LOI850 (%)	BGS	62	21.86 ± 2.29	2.08	72.79	c
	BRU	159	38.15 ± 1.47	1.56	80.65	b
	DAV	17	53.41 ± 3.57	19.58	76.55	a
	FLI	9	25.07 ± 6.84	4.69	52.73	c
	FRA	29	22.76 ± 3.63	1.78	74.56	c
	FRE	117	27.93 ± 1.48	2.30	69.72	c
	OTW	14	24.09 ± 4.39	1.17	45.60	c
Peat composition (%)	BGS	62	24.48 ± 04.29	0.00	87.50	b
	BRU	159	40.47 ± 02.65	0.00	87.50	a
	DAV	17	31.76 ± 06.48	0.00	62.50	ab
	FLI	9	20.00 ± 12.77	0.00	87.50	b
	FRA	29	17.24 ± 05.83	0.00	87.50	b
	FRE	117	33.33 ± 03.22	0.00	87.50	ab
	OTW	14	26.07 ± 09.94	0.00	87.50	ab
Sand composition (%)	BGS	62	35.36 ± 04.57	0.00	87.50	a
	BRU	159	9.58 ± 00.27	0.00	87.50	b
	DAV	17	5.59 ± 02.96	0.00	37.50	b
	FLI	9	49.17 ± 12.90	0.00	87.50	a
	FRA	29	40.60 ± 07.74	0.00	87.50	a
	FRE	117	14.36 ± 02.13	0.00	87.50	b
	OTW	14	47.68 ± 08.71	0.00	87.50	a
Loamy-soil composition (%)	BGS	62	22.06 ± 3.18	0.00	87.50	b
	BRU	159	23.71 ± 2.16	0.00	87.50	b
	DAV	17	27.50 ± 8.19	0.00	87.50	ab
	FLI	9	13.06 ± 6.55	0.00	62.50	b
	FRA	29	31.98 ± 6.51	0.00	87.50	ab
	FRE	117	36.88 ± 2.92	0.00	87.50	a
	OTW	14	11.07 ± 3.61	0.00	37.50	b

Bare ground – 2 levels of difference: regions BGS, FLI and OTW were similar in terms of means (Tukey group **a**), while all regions except for BGS displayed commonality (group **b**).

Organic layer depth – 2 levels of difference: region DAV was the sole member of group **a**; all regions except for DAV were similar in terms of means (Tukey group **b**).

pH – 4 levels of difference: regions FLI and OTW were similar (Tukey group **a**); regions BGS and OTW are similar in terms of means (group **b**); BGS and FRA exhibited similarity (group **c**), while regions BRU, DAV, FRA and FRE shared commonality (group **d**).

EC – 3 levels of difference: regions BGS, BRU and DAV had similar means (group **a**); regions BGS, DAV, FLI, FRE and OTW displayed similarity (Tukey group **b**), while the third Tukey group consisted of FLI, FRA and OTW (group **c**).

Moisture by volume – 3 levels of difference: regions BRU and DAV were similar (group **a**); BGS, BRU and FRE exhibited similar means (group **b**), and regions BGS, FLI, FRA, FRE and OTW displayed commonality in terms of means (Tukey group **c**).

Bulk density – 3 levels of difference: BGS, FLI, FRA and OTW had similar means (Tukey group **a**); regions BGS, FRA, FRE and OTW displayed similarity (group **b**), and BRU and DAV were not significantly different to each other (group **c**).

LOI550 – 3 levels of difference: regions DAV (group **a**) and BRU (Tukey group **b**) were significantly different to each other as well as to all other regions, while the remaining regions all displayed similar means (group **c**).

LOI850 – 3 levels of difference: reflection of LOI550.

Peat composition – 2 levels of difference: regions BRU, DAV, FRE and OTW displayed similar means (Tukey group **a**), while regions BGS, DAV, FRE and OTW exhibited commonality (group **b**).

Sand composition – 2 levels of difference: two distinct groupings were evident here, BGS, FLI, FRA and OTW had similar means (group **a**), and as a group were

significantly different to the remaining regions, BRU, DAV and FRE, which as a group, displayed similar means (Tukey group **b**).

Loamy-soil composition – 2 levels of difference: regions DAV, FRA and FRE had similar means (Tukey group **a**), whereas, BGS, BRU, DAV, FLI, FRA and OTW also displayed similar means (group **b**).

Summary – IMCRA regions HSD test

Edaphic factor pH displays the greatest level of difference with four levels, while EC, moisture by volume, bulk density, and both LOI treatments, each exhibit three levels of difference. The remaining five edaphic factors all display a difference level of two. This result can suggest that within context of IMCRA regionalisation, pH may be a suitable indicator of difference between regions, followed by those factors that display three levels of difference.

BOM coastal districts

From herein, the use of the term coastal districts, implies those districts delineated by BOM. The number of plots by soil type by coastal district are presented in Table 4.17. Data in this table is interpreted by column, therefore with a focus on districts.

Table 4.17: Number and percentage (%) of plots by soil type by coastal district. Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each coastal district.

Focus of table is coastal district, therefore data is viewed by column.

Soil type	Coastal districts																					
	Banks		EoF		lowerEAST		NORTH		NWEST		SE		SEinshore		SW		upperEAST		WEST		Totals	
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	0	0	0	0	**14**	**15**	**5**	**14**	**5**	**11**	0	0	10	7	0	0	2	6	0	0	36	9
2	1	7	0	0	**14**	**15**	3	9	3	7	0	0	**23**	**16**	0	0	1	3	0	0	**45**	**11**
3	0	0	0	0	**10**	**11**	3	9	4	9	0	0	**21**	**14**	0	0	**5**	**15**	0	0	**43**	**11**
4	**2**	**14**	**4**	**40**	1	1	**7**	**21**	**6**	**14**	0	0	3	2	0	0	1	3	**6**	**29**	30	7
5	1	7	**1**	**10**	**17**	**18**	3	9	2	5	**1**	**14**	6	4	0	0	**12**	**37**	**6**	**29**	**49**	**12**
6	**6**	**43**	0	0	**29**	**32**	**6**	**18**	4	9	**2**	**29**	**47**	**32**	0	0	**5**	**15**	**4**	**19**	**103**	**25**
7	**4**	**29**	0	0	6	6	**5**	**14**	**15**	**34**	0	0	9	6	0	0	**7**	**21**	**3**	**13**	**49**	**12**
8	0	0	**5**	**50**	2	2	2	6	**5**	**11**	**4**	**57**	**28**	**19**	**4**	**100**	0	0	**2**	**10**	**52**	**13**
Totals	14	100	10	100	73	100	34	100	44	100	7	100	147	100	4	100	33	100	21	100	407	100

Note: the percent column value is the percentage of plots of the total individual BOM coastal district within soil type, viewed by column.
For example, district **lowerEAST** (total 73 plots), **15% of plots are from soil type 1**, **15% from soil type 2**, **11% from soil type 3**, 1% from soil type 4, **18% from soil type 5**, **32% from soil type 6**, 6% from soil type 7, and 2% from soil type 8.

District codes: **Banks** = Banks Strait, **EoF** = East of Flinders Island, **lowerEAST** = Lower East Coast, **NORTH** = Central North Coast, **SE** = Southeast Coast, **SEinshore** = Southeast inshore, **SW** = Southwest Coast, **upperEAST** = Upper East Coast, **WEST** = Central West Coast. Terminology follows BOM (2017).

Four of the ten coastal districts, lowerEAST, NORTH, NWEST and SEinshore contain all soil types. The remaining districts, Banks, EoF, SE, SW, upperEAST and WEST, contain six, three, three, one, and five soil types respectively. It is accepted that that two of these districts, SE and SW, recorded a low number of sampled plots, which may suggest why these two districts do not display the full range of soil types. It is also possible that the districts may have a restricted range of soil types due to their place in the landscape. It is noted that SEinshore could be incorporated within SE as it is the inshore section of the main SE district (see Chapter 1, Figure 1.6). If this was the case, there would be no change to soil type dominance that is already attributed to SEinshore.

The coastal district of dominance by each soil type is presented in Table 4.18. Data in this table is viewed by row, therefore exhibiting a focus on soil type.

Table 4.18: Number and percentage (%) of plots of each soil type present within each coastal district. Soil type dominance determined within soil type (not within the district). Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each soil type.

Focus of table is soil type, therefore data is viewed by row.

Soil type	Coastal districts																				Totals	
	Banks		EoF		lowerEAST		NORTH		NWEST		SE		SEinshore		SW		upperEAST		WEST			
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	0	0	0	0	**14**	**39**	5	14	**5**	**14**	0	0	**10**	**28**	0	0	2	6	0	0	36	100
2	1	2	0	0	**14**	**31**	3	7	3	7	0	0	**23**	**51**	0	0	1	2	0	0	45	100
3	0	0	0	0	**10**	**23**	3	7	4	9	0	0	**21**	**49**	0	0	**5**	**12**	0	0	43	100
4	2	7	**4**	**13**	1	3	**7**	**23**	**6**	**20**	0	0	3	10	0	0	1	3	**6**	**20**	30	100
5	1	2	1	2	**17**	**35**	3	6	2	4	1	2	**6**	**12**	0	0	**12**	**24**	**6**	**12**	49	100
6	6	6	0	0	**9**	**28**	6	6	4	4	2	2	**47**	**46**	0	0	5	5	4	4	103	100
7	4	8	0	0	6	12	5	10	**15**	**31**	0	0	**9**	**18**	0	0	**7**	**14**	3	6	49	100
8	0	0	**5**	**10**	2	4	2	4	**5**	**10**	4	8	**28**	**54**	4	8	0	0	2	4	52	100
Totals	14	3	10	2	**93**	**23**	34	8	**44**	**11**	7	2	**147**	**37**	4	1	33	8	21	5	407	100

Note: the percent column value is the percentage of plots of the total individual soil type within each coastal district, viewed by row.
For example, **soil type 5** (total 49 plots), 2% of plots are in Banks districts, 2% EoF, **35% in lowerEAST**, 6% in NORTH, 4% in NWEST, 2% in SE, **12% in SEinshore**, 0% in SW, **24% in upperEAST** and **12% in WEST**.

District codes: **Banks** = Banks Strait, **EoF** = East of Flinders Island, **lowerEAST** = Lower East Coast, **NORTH** = Central North Coast, **SE** = Southeast Coast, **SEinshore** = Southeast inshore, **SW** = Southwest Coast, **upperEAST** = Upper East Coast, **WEST** = Central West Coast. Terminology follows BOM (2017).

No individual soil type is present across all coastal districts. Soil type 5 is the most dominant being present in all districts except for SW. The least dominant soil type is type 3, this being present in just five (lowerEAST, NORTH, NWEST, SEinshore and upperEAST) of the ten districts.

Soil type dominance (values in **blue**) is not widespread across all districts, being restricted to just four individual regions. Soil types 1 and 5 are most dominant in lowerEAST, soil type 4 in NORTH, soil type 7 NWEST, while soil types 2, 3, 6 and 8 are dominant in district SEinshore. This district (SEinshore) also exhibits two soil types as secondary dominance (values in **red**), thus being the most diverse district of all. It is noted that districts lowerEAST and SEinshore adjoin and represent a significant portion of Tasmania's east coast including Maria and Bruny Islands. It is recognised that these results may be somewhat skewed as 240 (59%) of the 407 sampled plots, are located within the two districts (lowerEAST and SEinshore).

Individual edaphic factors were aligned to individual coastal districts and tested using boxplots and ANOVA.

BOM coastal districts edaphic factors boxplots

Similar figure pairs, for LOI, display the same data range to aid better visualisation of results. Observations on Figures 4.62 to 4.72 are provided with Table 4.20 – Tukey groups.

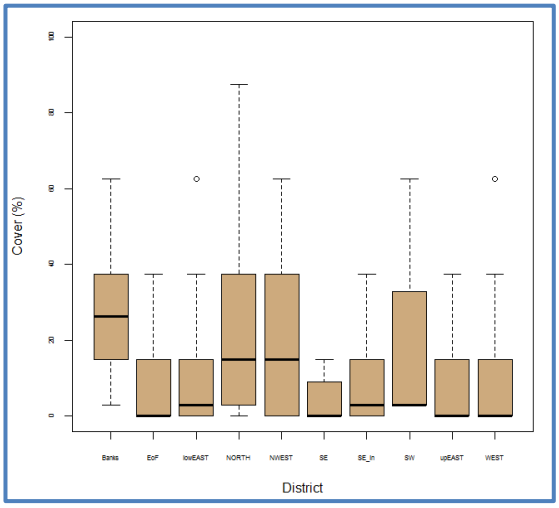


Figure 4.62: Coastal districts and bare ground.

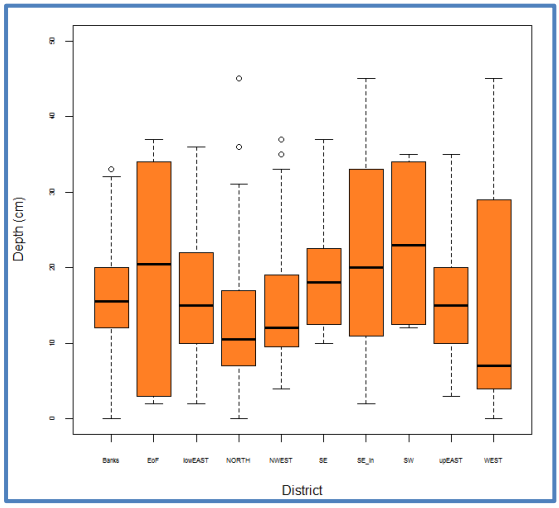


Figure 4.63: Coastal districts and organic layer depth.

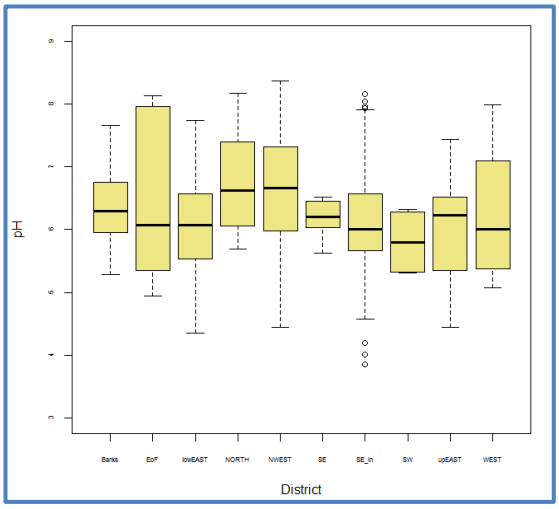


Figure 4.64: Coastal districts and pH.

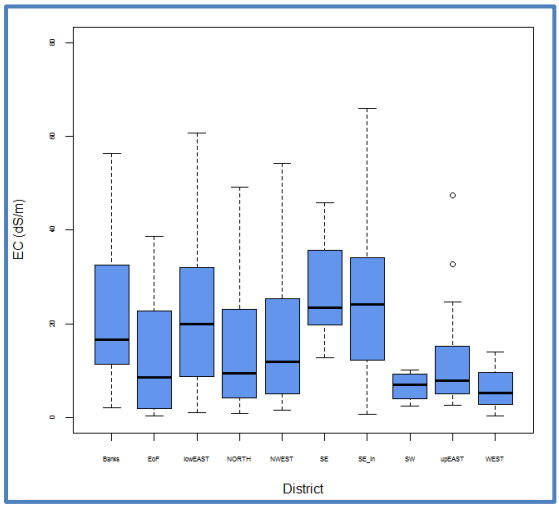


Figure 4.65: Coastal districts and EC.

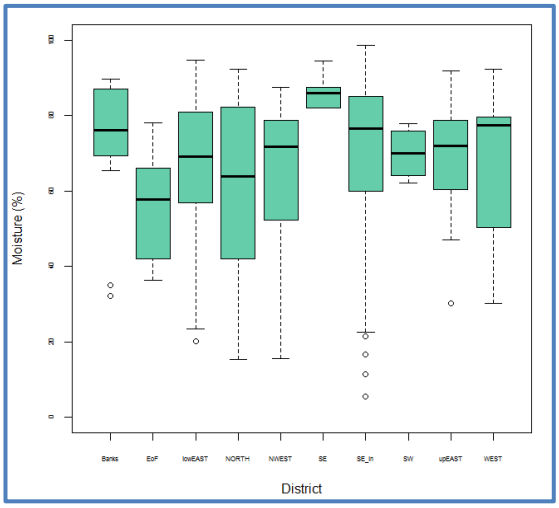


Figure 4.66: Coastal districts and moisture by volume.

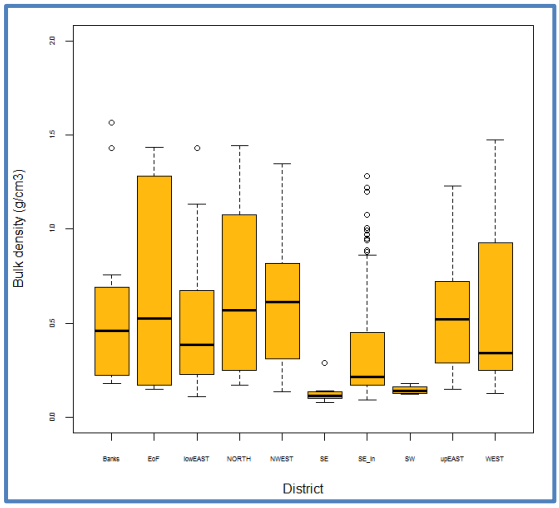


Figure 4.67: Coastal districts and bulk density.

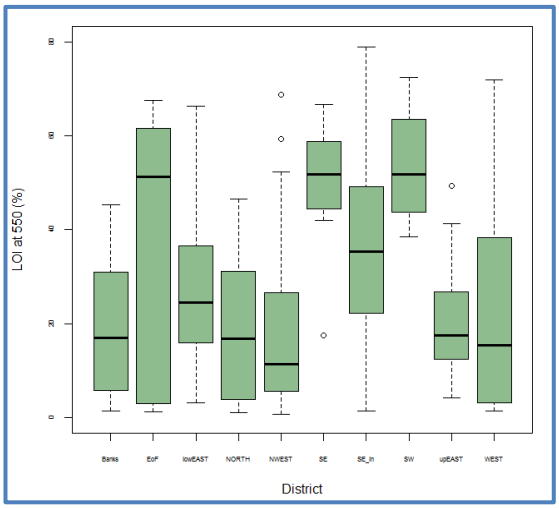


Figure 4.68: Coastal districts and LOI550.

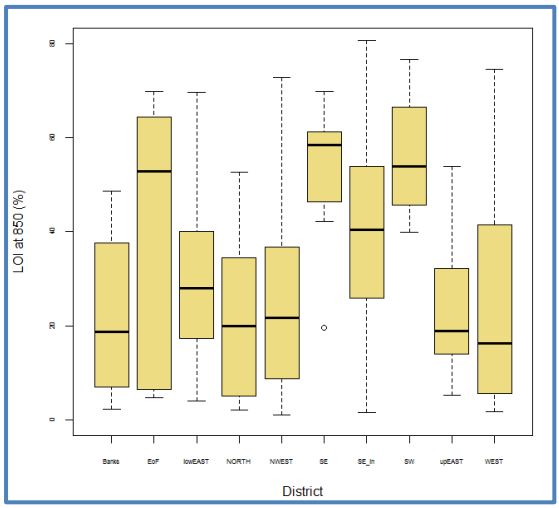


Figure 4.69: Coastal districts and LOI850.

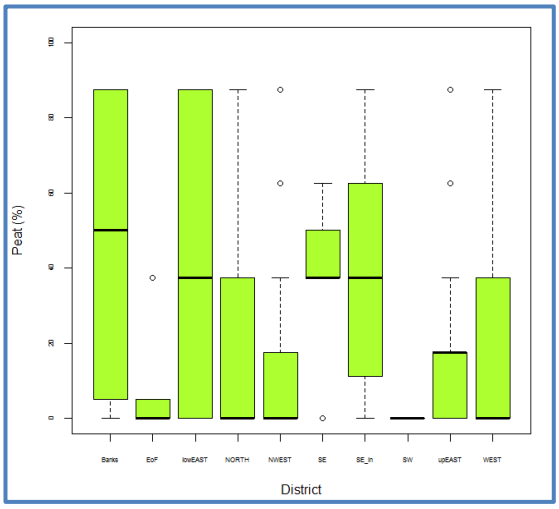


Figure 4.70: Coastal districts and peat composition.

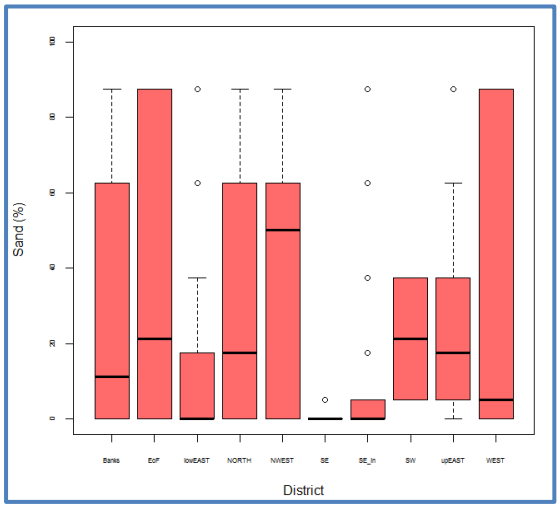


Figure 4.71: Coastal districts and sand composition.

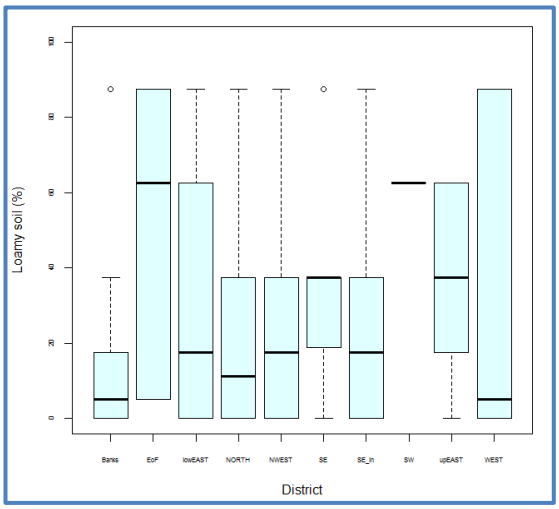


Figure 4.72: Coastal districts and loamy-soil composition.

District codes: **Banks** = Banks Strait,
EoF = East of Flinders Island,
lowerEAST = Lower East Coast,
NORTH = Central North Coast,
SE = Southeast Coast,
SEinshore = Southeast inshore,
SW = Southwest Coast,
upperEAST = Upper East Coast,
WEST = Central West Coast.
Terminology follows BOM (2017).

BOM coastal districts edaphic factors ANOVA

The ANOVA outputs of edaphic factors aligned to coastal districts are presented in Table 4.19 (following page).

Table 4.19: ANOVA results for soil type group edaphic factors aligned to coastal districts – sorted by order of boxplot.

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	9, 397	6.183	3.59e-08	***
Organic layer depth	Depth	9, 397	3.378	5.24e-04	***
pH	pH	9, 397	3.991	6.77e-05	***
EC (proxy for salinity)	EC	9, 397	7.042	1.82e-09	***
Moisture by volume	M_vol	9, 397	3.084	1.36e-03	**
Bulk density	Bul_den	9, 397	6.866	3.35e-09	***
LOI550	LOI_550	9, 397	9.897	9.95e-14	***
LOI850	LOI_850	9, 397	9.285	8.01e-13	***
Peat composition	Peat	9, 397	4.761	4.91e-06	***
Sand composition	Sand	9, 397	10.380	1.92e-14	***
Loamy-soil composition	L.soil	9, 397	3.952	7.71e-05	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

All edaphic factors have significant differences between coastal districts. The low p-value ($p<0.001$) for the majority (excludes moisture by volume), indicates that there is at least one district within each edaphic factor that is significantly different to all other coastal districts within that factor.

Tukey's HSD test results are presented in Table 4.20.

Table 4.20: Coastal district means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at $p<0.05$. Coastal district order within each edaphic factor is alphabetical.

District codes: **Banks** = Banks Strait, **EoF** = East of Flinders Island, **lowerEAST** = Lower East Coast, **NORTH** = Central North Coast, **SE** = Southeast Coast, **SEinshore** = Southeast inshore, **SW** = Southwest Coast, **upperEAST** = Upper East Coast, **WEST** = Central West Coast. Terminology follows BOM (2017).

Edaphic factor	Coastal district	*n*	Mean ± Std error	Min	Max	Tukey group
Bare ground (%)	Banks	14	27.18 ± 04.30	3.00	62.50	a
	EoF	10	7.05 ± 03.90	0.00	37.50	b
	lowerEAST	93	10.22 ± 01.34	0.00	62.50	b
	NORTH	34	22.03 ± 03.41	0.00	87.50	a
	NWEST	44	15.98 ± 02.62	0.00	62.50	ab
	SE	7	4.71 ± 02.69	0.00	15.00	b
	SEinshore	147	7.69 ± 00.92	0.00	37.50	b
	SW	4	17.88 ± 14.88	3.00	62.50	ab
	upperEAST	33	9.59 ± 02.35	0.00	37.50	b
	WEST	21	14.88 ± 04.50	0.00	62.50	ab

Edaphic factor	Coastal district	*n*	Mean ± Std error	Min	Max	Tukey group
Organic layer (cm)	Banks	14	16.86 ± 2.68	0.00	33.00	ab
	EoF	10	19.20 ± 4.94	2.00	37.00	ab
	lowerEAST	93	16.45 ± 0.93	2.00	36.00	ab
	NORTH	34	13.59 ± 1.97	0.00	45.00	ab
	NWEST	44	15.11 ± 1.33	4.00	37.00	ab
	SE	7	19.29 ± 3.52	10.00	37.00	ab
	SEinshore	147	21.90 ± 1.01	2.00	45.00	a
	SW	4	23.25 ± 6.22	12.00	35.00	a
	upperEAST	33	16.58 ± 1.27	3.00	35.00	ab
	WEST	21	16.76 ± 3.51	0.00	45.00	ab
pH	Banks	14	6.38 ± 0.16	5.29	7.66	ab
	EoF	10	6.47 ± 0.42	4.94	8.13	ab
	lowerEAST	93	6.04 ± 0.08	4.36	7.74	b
	NORTH	34	6.80 ± 0.14	5.69	8.17	a
	NWEST	44	6.62 ± 0.14	4.45	8.36	a
	SE	7	6.18 ± 0.13	5.62	6.52	ab
	SEinshore	147	6.14 ± 0.07	3.86	8.15	b
	SW	4	5.81 ± 0.28	5.31	6.32	b
	upperEAST	33	6.10 ± 0.13	4.45	7.44	b
	WEST	21	6.24 ± 0.21	5.07	7.99	ab
EC (dS/m)	Banks	14	21.89 ± 4.45	2.09	56.29	ab
	EoF	10	12.67 ± 4.10	0.40	38.75	ab
	lowerEAST	93	22.87 ± 1.69	1.16	60.70	a
	NORTH	34	15.21 ± 2.44	0.99	49.18	ab
	NWEST	44	16.73 ± 2.18	1.65	54.15	ab
	SE	7	27.64 ± 4.86	12.82	45.85	a
	SEinshore	147	24.76 ± 1.25	0.80	65.90	a
	SW	4	6.64 ± 1.67	2.48	10.11	ab
	upperEAST	33	11.93 ± 1.72	2.73	47.44	ab
	WEST	21	6.00 ± 0.96	0.48	14.07	b
Moisture by volume (%)	Banks	14	72.83 ± 4.99	32.20	89.65	ab
	EoF	10	56.29 ± 4.62	36.36	78.05	b
	lowerEAST	93	66.31 ± 1.83	20.20	94.68	ab
	NORTH	34	61.47 ± 3.65	15.29	92.19	b
	NWEST	44	62.04 ± 3.46	15.60	87.44	b
	SE	7	85.93 ± 1.71	81.92	94.40	a
	SEinshore	147	71.74 ± 1.50	5.54	98.60	ab
	SW	4	70.00 ± 3.61	62.03	77.88	ab
	upperEAST	33	69.78 ± 2.47	30.22	91.73	ab
	WEST	21	69.81 ± 4.13	30.23	92.35	ab

Edaphic factor	Coastal district	*n*	Mean ± Std error	Min	Max	Tukey group
Bulk density (g/cm^3)	Banks	14	0.56 ± 0.12	0.18	1.56	ab
	EoF	10	0.70 ± 0.18	0.15	1.43	a
	lowerEAST	93	0.48 ± 0.03	0.11	1.43	ab
	NORTH	34	0.68 ± 0.08	0.17	1.44	a
	NWEST	44	0.58 ± 0.05	0.14	1.35	a
	SE	7	0.14 ± 0.03	0.08	0.29	b
	SEinshore	147	0.35 ± 0.02	0.09	1.28	b
	SW	4	0.15 ± 0.01	0.12	0.18	b
	upperEAST	33	0.55 ± 0.05	0.15	1.23	ab
	WEST	21	0.54 ± 0.10	0.13	1.47	ab
LOI550 (%)	Banks	14	20.10 ± 4.14	1.53	45.36	b
	EoF	10	36.36 ± 9.52	1.26	67.45	ab
	lowerEAST	93	25.83 ± 1.48	3.20	66.27	b
	NORTH	34	19.28 ± 2.64	1.15	46.58	b
	NWEST	44	18.42 ± 2.54	0.81	68.77	b
	SE	7	48.90 ± 6.14	17.47	66.66	a
	SEinshore	147	35.43 ± 1.45	1.36	78.85	ab
	SW	4	53.61 ± 7.09	38.57	72.41	a
	upperEAST	33	20.37 ± 1.92	4.27	49.30	b
	WEST	21	22.29 ± 4.96	1.44	71.88	b
LOI850 (%)	Banks	14	22.35 ± 4.48	2.30	48.66	b
	EoF	10	39.26 ± 9.28	4.69	69.72	ab
	lowerEAST	93	28.84 ± 1.62	4.15	69.59	ab
	NORTH	34	21.99 ± 2.87	2.08	52.73	b
	NWEST	44	23.97 ± 2.72	1.17	72.79	b
	SE	7	51.85 ± 6.35	19.58	69.86	a
	SEinshore	147	39.37 ± 1.53	1.56	80.65	a
	SW	4	56.08 ± 7.64	39.93	76.55	a
	upperEAST	33	22.55 ± 2.07	5.32	53.84	b
	WEST	21	24.31 ± 4.94	1.78	74.56	b
Peat composition (%)	Banks	14	46.61 ± 10.79	0.00	87.50	a
	EoF	10	5.25 ± 03.66	0.00	37.50	ab
	lowerEAST	93	39.49 ± 03.83	0.00	87.50	a
	NORTH	34	24.49 ± 06.12	0.00	87.50	ab
	NWEST	44	17.10 ± 04.48	0.00	87.50	ab
	SE	7	39.29 ± 07.92	0.00	62.50	ab
	SEinshore	147	40.61 ± 02.65	0.00	87.50	a
	SW	4	00.00 ± 00.00	0.00	0.00	ab
	upperEAST	33	22.12 ± 05.05	0.00	87.50	ab
	WEST	21	23.81 ± 07.61	0.00	87.50	ab

Edaphic factor	Coastal district	*n*	Mean ± Std error	Min	Max	Tukey group
Sand composition (%)	Banks	14	34.11 ± 10.15	0.00	87.50	ab
	EoF	10	39.25 ± 13.60	0.00	87.50	a
	lowerEAST	93	10.56 ± 02.18	0.00	87.50	bc
	NORTH	34	33.53 ± 06.12	0.00	87.50	ab
	NWEST	44	42.50 ± 05.24	0.00	87.50	a
	SE	7	0.71 ± 00.71	0.00	5.00	c
	SEinshore	147	9.25 ± 01.72	0.00	87.50	c
	SW	4	21.25 ± 09.38	5.00	37.50	abc
	upperEAST	33	23.41 ± 04.10	0.00	87.50	abc
	WEST	21	32.98 ± 08.45	0.00	87.50	ab
Loamy-soil composition (%)	Banks	14	12.86 ± 06.40	0.00	87.50	ab
	EoF	10	49.50 ± 12.49	5.00	87.50	a
	lowerEAST	93	32.28 ± 03.49	0.00	87.50	ab
	NORTH	34	20.51 ± 04.30	0.00	87.50	ab
	NWEST	44	21.88 ± 03.44	0.00	87.50	ab
	SE	7	33.93 ± 00.15	0.00	87.50	ab
	SEinshore	147	22.04 ± 02.17	0.00	87.50	ab
	SW	4	62.50 ± 00.00	62.50	62.50	a
	upperEAST	33	39.55 ± 03.88	0.00	62.50	a
	WEST	21	35.71 ± 08.44	0.00	87.50	ab

Bare ground – 2 levels of difference: similarity of means is observed within two Tukey groups: Banks, NORTH, NWEST, SW and WEST, all in group **a,** whereas coastal districts EoF, lowerEAST, NWEST, SE, SEinshore, SW, upperEAST and WEST comprised group **b**.

Organic layer depth – 2 levels of difference: all coastal districts had similar means and comprised Tukey group **a,** while all districts with the exclusion of SEinshore and SE displayed similarity (group **b**).

pH – 2 levels of difference: six districts, Banks, EoF, NORTH, NWEST, SE and WEST displayed similarity (group **a**); all districts except for NORTH and NWEST were similar in terms of means (Tukey group **b**).

EC – 2 levels of difference: all coastal districts, to the exclusion of WEST, exhibited similarity in terms of means (Tukey group **a**), while all districts, apart from lowerEAST, SE and SEinshore, had similar means (group **b**).

Moisture by volume – 2 levels of difference: all districts except for EoF, NORTH and NWEST displayed similarity (Tukey group **a**), whereas all districts, except for SE, had similar means (group **b**).

Bulk density – 2 levels of difference: all districts to the exception of SE, SEinshore and SW exhibited commonality (group **a**), while all coastal districts to the exclusion of EoF, NORTH and NWEST shared similar means Tukey group **b**).

LOI550 – 2 levels of difference: four coastal districts, EoF, SE, SEinshore and SW displayed similar means (Tukey group **a**), and all districts, except for two, SE and SW, were included in Tukey group **b**.

LOI850 – 2 levels of difference: a repeat of the above (see LOI550) except for the inclusion of district lowerEAST in the Tukey group **a**, and the inclusion of SEinshore in Tukey group **b**.

Peat composition – 2 levels of difference: all districts displayed similar means (Tukey group **a**), while all districts except for Banks, lowerEAST and SEinshore had similar means (group **b**).

Sand composition – 3 levels of difference: all coastal districts to the exclusion of lowerEAST, SE and SEinshore displayed similar means (group **a**); all districts except for EoF, NWEST, SE and SEinshore exhibited similar means (Tukey group **b**), while districts lowerEAST, SE, SEinshore, SW and upperEAST displayed commonality in terms of means (group **c**).

Loamy-soil composition – 2 levels of difference: all districts shared similar means (Tukey group **a**), while again all, except for EoF, SW and upperEAST, displayed similarity group **b**).

Summary – BOM coastal districts HSD test

A clear interpretation drawn from the BOM coastal districts Tukey HSD test is that most edaphic factors exhibit similar results displaying only two levels of difference, except for sand composition, which displays three levels. It is difficult to determine a hard and fast conclusion in respect to which edaphic factor or factors are suitable indicators of difference between coastal districts, as in all cases difference levels are very

low. However, interesting conclusions can be drawn from the Tukey grouping results. In respect of sand composition, districts SW, WEST, NWEST, NORTH, Banks, EoF and upperEAST make up Tukey group **a**, and in a geographic sense, all adjoin around the Tasmanian coastline. Similarly, upperEAST, lowerEAST, SE, SEinshore and SW make up Tukey group **b**, and again are all geographically contiguous. A similar grouping occurs in EC, where districts SW, WEST, NWEST, NORTH, Banks, EoF and upperEAST are all in the same Tukey group (**b**) and geographically adjoin.

Geographic regions

The number of plots by soil type by geographic regions (Edgar *et al.* 1999) are presented in Table 4.21 (following page). Data in this table is interpreted by column, therefore with a focus on regions.

Only two of the eight geographic regions, EAST and SE, contain all soil types. The remaining six regions, eastNORTH, FUR, KING, NWEST, SOUTH and WEST contain six, five, six, seven three and six soil types respectively. However, two of those regions, FUR and SOUTH, each record just two percent of the total number of plots, which may suggest as to why these regions have a low diversity of soil types. Yet, it is also possible that they may have a limited range of soil types due to their position in the landscape.

The geographic region of dominance by each soil type is presented in Table 4.22 (page 4.79). Data in this table is viewed by row, therefore exhibiting a focus on soil type.

Table 4.21: Number and percentage (%) of plots by soil type by geographic region. Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each geographic region.

Focus of table is geographic region, therefore data is viewed by column.

	Geographic regions																	
Soil type	**EAST**		**eastNORTH**		**FUR**		**KING**		**NWEST**		**SE**		**SOUTH**		**WEST**		**Totals**	
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	**16**	**13**	**4**	**16**	**1**	**11**	1	7	0	0	10	6	0	0	**4**	**14**	36	9
2	**12**	**10**	1	4	**2**	**22**	1	7	3	8	**26**	**16**	0	0	0	0	**45**	**11**
3	11	9	0	0	**1**	**11**	0	0	**6**	**16**	**25**	**16**	0	0	0	0	**43**	**11**
4	3	2	**6**	**24**	**4**	**44**	**2**	**14**	3	8	3	2	0	0	**9**	**31**	30	7
5	**30**	**24**	0	0	**1**	**11**	1	7	3	8	6	4	**1**	**14**	**7**	**24**	**49**	**12**
6	**35**	**28**	**5**	**20**	0	0	**3**	**21**	**6**	**16**	**48**	**30**	**2**	**29**	**4**	**14**	**103**	**25**
7	**13**	**10**	**8**	**32**	0	0	**6**	**43**	**10**	**27**	9	6	0	0	3	10	**49**	**12**
8	6	5	1	4	0	0	0	0	**6**	**16**	**33**	**21**	**4**	**57**	2	7	**52**	**13**
Totals	126	100	25	100	9	100	14	100	37	100	160	100	7	100	29	100	407	100

Note: the percent column value is the percentage of plots of the total individual geographic region within soil type, viewed by column. For example, **SE** (total 160 plots), 6% of plots are from soil type 1, **16% from soil type 2**, **16% from soil type 3**, 2% from soil type 4, 4% from soil type 5, **30% from soil type 6**, 6% from soil type 7, and **21% from soil type 8**.

Region codes: **EAST** = East coast, **eastNORTH** = East (section) north coast, **FUR** = Furneaux Group, **KIN** = King Island, **NWEST** = North west, **SE** = South east, **SOUTH** = South coast, **WEST** = West Coast. Terminology follows Edgar (1999).

Table 4.22: Number and percentage (%) of plots of each soil type present within each geographic region. Soil type dominance determined within soil type (not within the region). Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each soil type.

Focus of table is soil type, therefore data is viewed by row.

Soil type	Geographic region																Totals	
	EAST		eastNORTH		FUR		KING		NWEST		SE		SOUTH		WEST			
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	**16**	**44**	**4**	**11**	1	3	1	3	0	0	**10**	**28**	0	0	**4**	**11**	36	100
2	**12**	**27**	1	2	2	4	1	2	3	7	**26**	**58**	0	0	0	0	45	100
3	**11**	**26**	0	0	1	2	0	0	**6**	**14**	**25**	**58**	0	0	0	0	43	100
4	**3**	**10**	**6**	**20**	**4**	**13**	2	7	**3**	**10**	**3**	**10**	0	0	**9**	**30**	30	100
5	**30**	**61**	0	0	1	2	1	2	3	6	**6**	**12**	1	2	**7**	**14**	49	100
6	**35**	**34**	5	5	0	0	3	3	6	6	**48**	**47**	2	2	4	4	103	100
7	**13**	**27**	**8**	**16**	0	0	**6**	**12**	**10**	**20**	**9**	**18**	0	0	3	6	49	100
8	**6**	**12**	1	2	0	0	0	0	**6**	**12**	**33**	**63**	4	8	2	4	52	100
Totals	**126**	**31**	25	6	9	2	14	3	**37**	**9**	**160**	**39**	7	2	29	7	407	100

Note: the percent column value is the percentage of plots of the total individual soil type within each geographic region, viewed by row. For example, **soil type 5** (total 49 plots), **61% of plots are in EAST region**, 0% in eastNORTH, 2% in FUR, 2% in KING, 6% in NWEST, **12% in SE**, 2% in SOUTH, and **14% in WEST**.

Region codes: **EAST** = East coast, **eastNORTH** = East (section) north coast, **FUR** = Furneaux Group, **KIN** = King Island, **NWEST** = North west, **SE** = South east, **SOUTH** = South coast, **WEST** = West Coast. Terminology follows Edgar (1999).

In all cases, individual soil types are not spread across all geographic regions. The most widespread are types 4 and 5, which are present in all except one region each. The most restricted soil type is group 3, which is not present in regions eastNORTH, KING, South and WEST, and has a very limited presence in region FUR, being present in just one plot.

Soil type dominance (values in **blue**) is very restricted, basically to two regions, EAST and SE, with SE exhibiting the greatest dominance. However, EAST displays a greater secondary dominance (values in **red**) for three soil types, while in SE, secondary dominance exists for two soil types. Interestingly, soil type 4 displays dominance in the WEST region, with a secondary dominance in eastNORTH, these two regions do not adjoin. Two regions, EAST and SE, adjoin and represent the entire east coast of Tasmania from Cape Portland (the northeast tip) to Cockle Creek and include Maria and Bruny Islands. It is assumed that these results may be somewhat distorted as of the 407 plots sampled, 286 (70%) are located in these two regions.

Individual edaphic factors were aligned to geographic regions and tested using boxplots and ANOVA.

Geographic regions edaphic factors boxplots

Note: similar figure pairs, for LOI, display the same data range to aid better visualisation of results. Observations on Figures 4.73 to 4.83 are provided with Table 4.24 – Tukey groups.

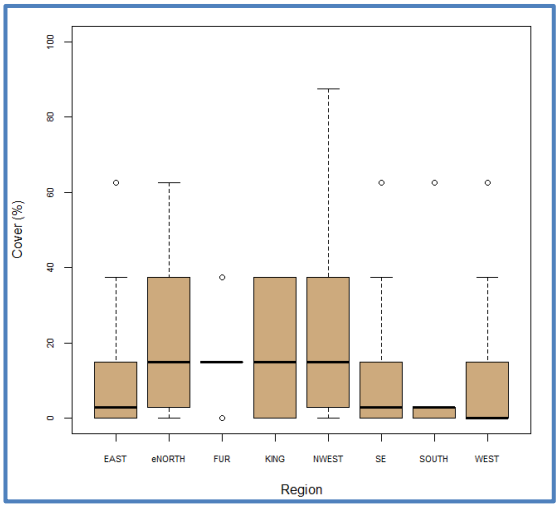


Figure 4.73: Geographic regions and bare ground.

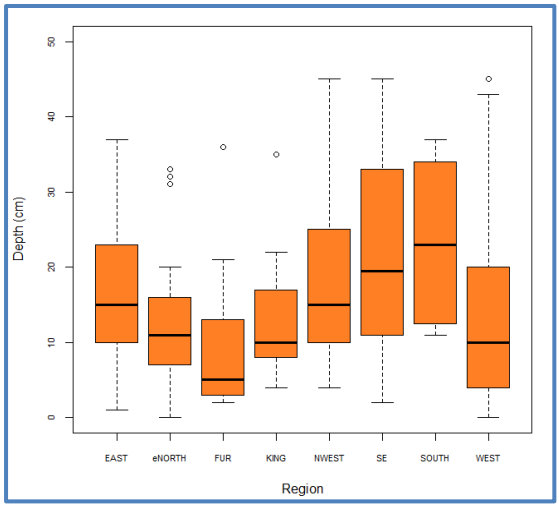


Figure 4.74: Geographic regions and organic layer depth.

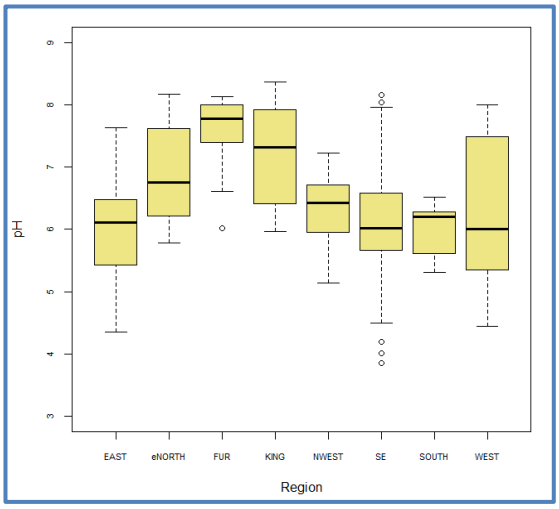


Figure 4.75: Geographic regions and pH.

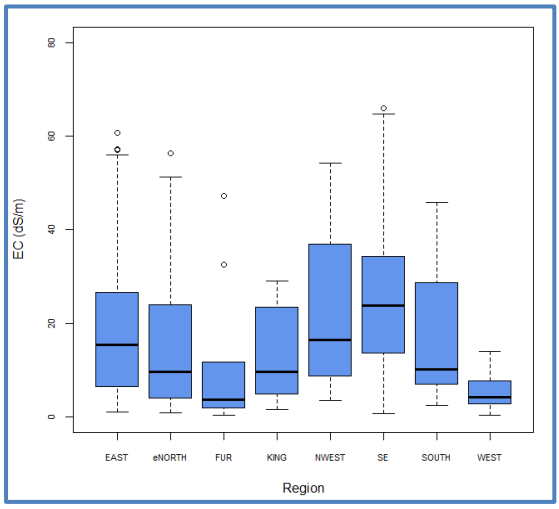


Figure 4.76: Geographic regions and EC.

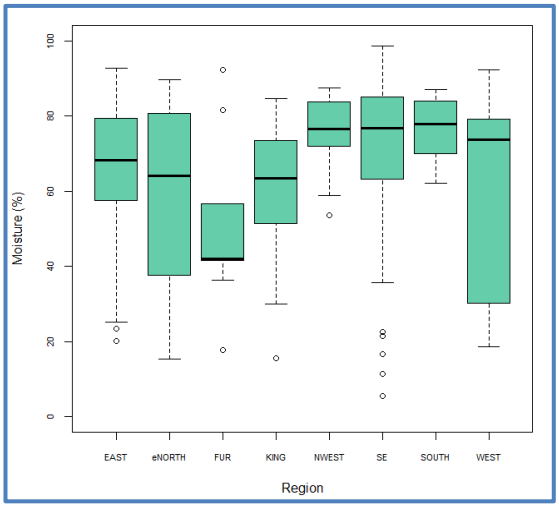


Figure 4.77: Geographic regions and moisture by volume.

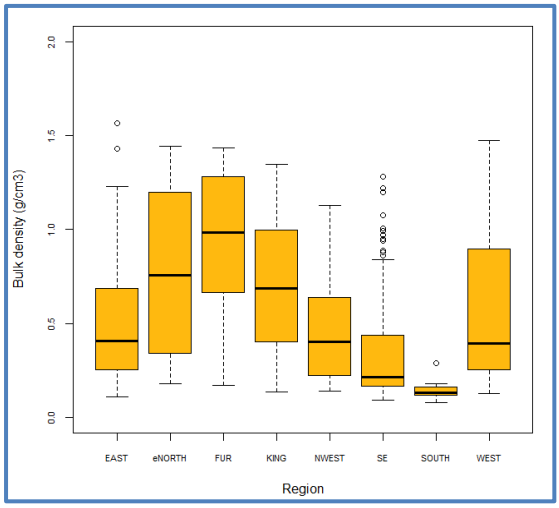


Figure 4.78: Geographic regions and bulk density.

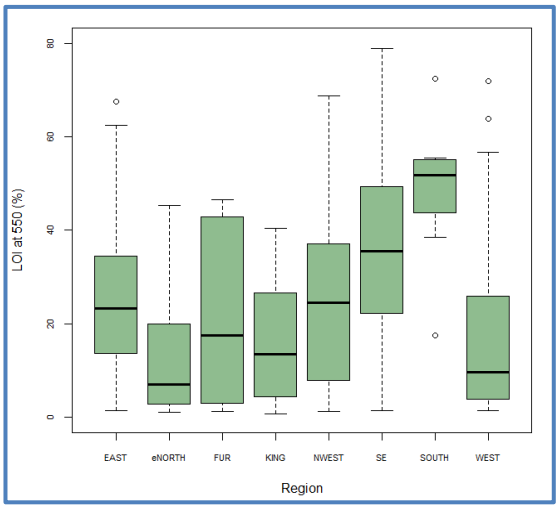


Figure 4.79: Geographic regions and LOI550.

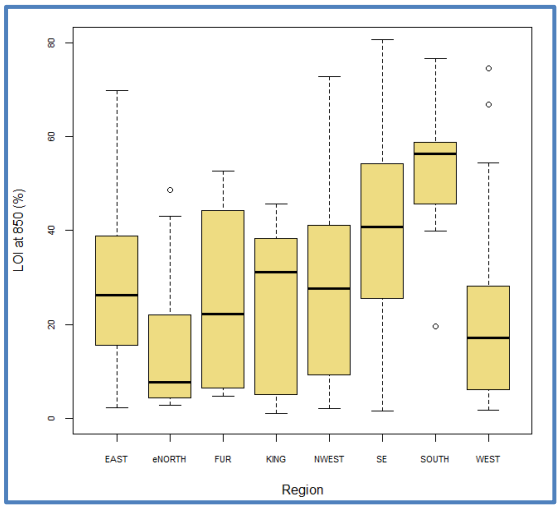


Figure 4.80: Geographic regions and LOI850.

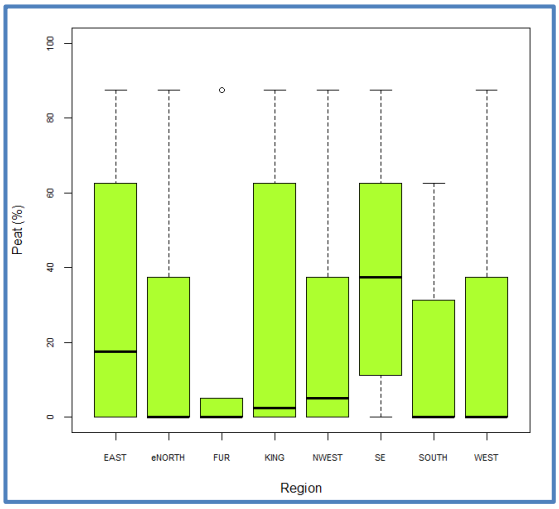


Figure 4.81: Geographic regions and peat composition.

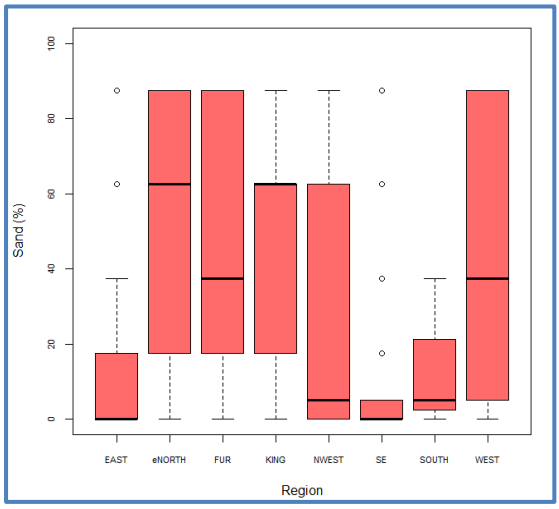


Figure 4.82: Geographic regions and sand composition.

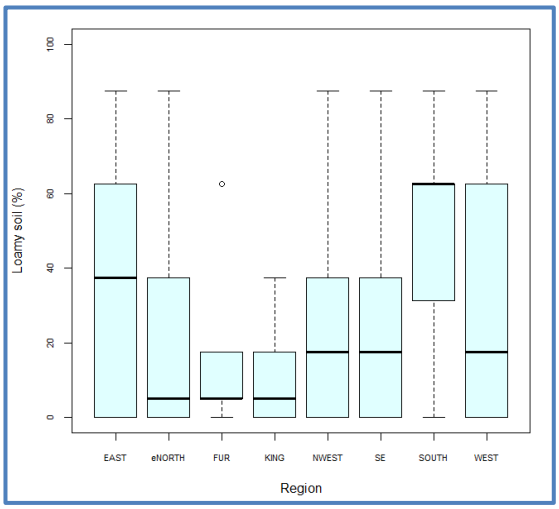


Figure 4.83: Geographic regions and loamy-soil composition.

Region codes: **EAST** = East coast, **eastNORTH** = East (section) north coast, **FUR** = Furneaux Group, **KIN** = King Island, **NWEST** = North west, **SE** = South east, **SOUTH** = South coast, **WEST** = West Coast. Terminology follows Edgar (1999).

Geographic regions edaphic factors ANOVA

The ANOVA outputs of edaphic factors aligned to geographic regions are presented in Table 4.23 (following page).

Each edaphic factor has significant differences between geographic regions. The low p-value ($p<0.001$) for most (excludes peat composition) indicates that there is at least one group within each edaphic factor that is significantly different to all other geographic groups within that factor.

Table 4.23: ANOVA results for soil type group edaphic factors aligned to geographic regions – sorted by order of boxplots.

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	7, 399	6.540	2.55e-07	***
Organic layer depth	Depth	7, 399	4.679	4.67e-05	***
pH	pH	7, 399	10.770	1.90e-12	***
EC (proxy for salinity)	EC	7, 399	8.229	2.21e-09	***
Moisture by volume	M_vol	7, 399	6.455	3.23e-07	***
Bulk density	Bul_den	7, 399	12.530	1.53e-14	***
LOI550	LOI_550	7, 399	12.450	1.90e-14	***
LOI850	LOI_850	7, 399	11.830	1.04e-13	***
Peat composition	Peat	7, 399	3.179	2.76e-03	**
Sand composition	Sand	7, 399	15.830	<2.00e-16	***
Loamy-soil composition	L.soil	7, 399	5.324	7.74e-06	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

Tukey's HSD test results are presented in Table 4.24.

Table 4.24: Geographic group means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at p<0.05. Group order within each edaphic factor is alphabetical.

Region codes: **EAST** = East coast, **eastNORTH** = East (section) north coast, **FUR** = Furneaux Group, **KIN** = King Island, **NWEST** = North west, **SE** = South east, **SOUTH** = South coast, **WEST** = West Coast. Terminology follows Edgar (1999).

Edaphic factor	Geographic region	*n*	Mean ± Std error	Min	Max	Tukey group
Bare ground (%)	EAST	126	10.23 ± 1.18	0.00	62.50	b
	eastNORTH	25	20.92 ± 3.48	0.00	62.50	a
	FUR	9	16.67 ± 4.47	0.00	37.50	ab
	KING	14	16.61 ± 4.60	0.00	37.50	ab
	NWEST	37	22.55 ± 3.30	0.00	87.50	a
	SE	160	7.96 ± 0.92	0.00	62.50	b
	SOUTH	7	10.21 ± 8.73	0.00	62.50	b
	WEST	29	11.81 ± 3.43	0.00	62.50	ab
Organic layer (cm)	EAST	126	17.06 ± 0.81	1.00	37.00	ab
	eastNORTH	25	12.72 ± 2.04	0.00	33.00	ab
	FUR	9	10.67 ± 3.80	2.00	36.00	ab
	KING	14	13.50 ± 2.19	4.00	35.00	ab
	NWEST	37	17.78 ± 1.77	4.00	45.00	ab
	SE	160	21.44 ± 0.95	2.00	45.00	a
	SOUTH	7	23.43 ± 4.37	11.00	37.00	a
	WEST	29	14.72 ± 2.61	0.00	45.00	ab

Edaphic factor	Geographic region	*n*	Mean ± Std error	Min	Max	Tukey group
pH	EAST	126	6.01 ± 0.06	4.36	7.63	c
	eastNORTH	25	6.89 ± 0.16	5.78	8.17	ab
	FUR	9	7.50 ± 0.24	6.02	8.13	a
	KING	14	7.21 ± 0.15	5.96	8.36	a
	NWEST	37	6.30 ± 0.08	5.14	7.22	bc
	SE	160	6.15 ± 0.07	3.86	8.15	c
	SOUTH	7	5.97 ± 0.18	5.31	6.52	c
	WEST	29	6.29 ± 0.21	4.45	8.00	bc
EC (dS/m)	EAST	126	19.05 ± 1.34	1.16	60.70	b
	eastNORTH	25	15.73 ± 3.08	0.99	56.29	bc
	FUR	9	12.28 ± 5.53	0.40	47.30	bc
	KING	14	13.02 ± 2.75	1.65	29.06	bc
	NWEST	37	21.80 ± 2.53	3.60	54.15	ab
	SE	160	25.08 ± 1.19	0.80	65.90	a
	SOUTH	7	18.56 ± 7.01	2.48	45.85	bc
	WEST	29	5.43 ± 0.72	0.48	14.07	c
Moisture by volume (%)	EAST	126	66.56 ± 1.51	20.20	92.71	ab
	eastNORTH	25	59.58 ± 4.41	15.29	89.65	ab
	FUR	9	50.82 ± 7.67	17.82	92.19	ab
	KING	14	57.75 ± 5.27	15.60	84.58	ab
	NWEST	37	75.80 ± 1.44	53.60	87.44	a
	SE	160	72.44 ± 1.41	5.54	98.60	a
	SOUTH	7	76.41 ± 3.63	62.03	86.95	a
	WEST	29	58.40 ± 4.84	18.61	92.35	ab
Bulk density (g/cm^3)	EAST	126	0.50 ± 0.03	0.11	1.56	b
	eastNORTH	25	0.77 ± 0.09	0.18	1.44	a
	FUR	9	0.90 ± 0.16	0.17	1.43	a
	KING	14	0.70 ± 0.10	0.14	1.35	ab
	NWEST	37	0.47 ± 0.05	0.14	1.13	bc
	SE	160	0.34 ± 0.02	0.09	1.28	c
	SOUTH	7	0.15 ± 0.03	0.08	0.29	c
	WEST	29	0.58 ± 0.07	0.13	1.47	ab
LOI550 (%)	EAST	126	25.31 ± 1.31	1.53	67.45	b
	eastNORTH	25	13.62 ± 2.77	1.15	45.36	c
	FUR	9	20.19 ± 6.67	1.26	46.58	bc
	KING	14	15.19 ± 3.27	0.81	40.35	bc
	NWEST	37	23.75 ± 2.93	1.27	68.77	bc
	SE	160	35.77 ± 1.41	1.36	78.85	a
	SOUTH	7	48.45 ± 6.42	17.47	72.41	a
	WEST	29	19.08 ± 3.75	1.44	71.88	bc

Edaphic factor	Geographic region	*n*	Mean ± Std error	Min	Max	Tukey group
LOI850 (%)	EAST	126	28.07 ± 1.41	2.30	69.72	b
	eastNORTH	25	15.32 ± 2.88	2.76	48.66	c
	FUR	9	25.07 ± 6.84	4.69	52.73	bc
	KING	14	24.09 ± 4.39	1.17	45.60	bc
	NWEST	37	26.28 ± 3.13	2.08	72.79	bc
	SE	160	39.64 ± 1.48	1.56	80.65	a
	SOUTH	7	51.64 ± 6.74	19.58	76.55	a
	WEST	29	22.76 ± 3.63	1.78	74.56	bc
Peat composition (%)	EAST	126	33.53 ± 03.15	0.00	87.50	ab
	eastNORTH	25	25.60 ± 07.12	0.00	87.50	ab
	FUR	9	20.00 ± 12.77	0.00	87.50	ab
	KING	14	26.07 ± 09.94	0.00	87.50	ab
	NWEST	37	23.72 ± 05.41	0.00	87.50	ab
	SE	160	40.78 ± 02.55	0.00	87.50	a
	SOUTH	7	17.86 ± 11.53	0.00	62.50	ab
	WEST	29	17.24 ± 05.83	0.00	87.50	b
Sand composition (%)	EAST	126	14.35 ± 02.08	0.00	87.50	bc
	eastNORTH	25	47.50 ± 07.02	0.00	87.50	a
	FUR	9	49.17 ± 12.90	0.00	87.50	a
	KING	14	47.68 ± 08.71	0.00	87.50	a
	NWEST	37	27.16 ± 05.69	0.00	87.50	ab
	SE	160	8.75 ± 01.59	0.00	87.50	c
	SOUTH	7	12.86 ± 06.42	0.00	37.50	bc
	WEST	29	40.60 ± 07.04	0.00	87.50	a
Loamy-soil composition (%)	EAST	126	37.44 ± 02.87	0.00	87.50	a
	eastNORTH	25	16.50 ± 04.58	0.00	87.50	ab
	FUR	9	13.06 ± 06.55	0.00	62.50	ab
	KING	14	11.07 ± 03.61	0.00	37.50	ab
	NWEST	37	25.81 ± 04.27	0.00	87.50	ab
	SE	160	21.86 ± 02.05	0.00	87.50	ab
	SOUTH	7	48.21 ± 12.92	0.00	87.50	a
	WEST	29	31.98 ± 06.51	0.00	87.50	ab

Bare ground – 2 levels of difference: geographic regions eastNORTH, FUR, KING, NWEST and WEST had similar means (Tukey group **a**); all regions apart from eastNORTH and NWEST displayed similar means (group **b**). Incidentally, members of each of the two individual Tukey groups (**a** and **b**) were geographically contiguous.

Organic layer depth – 2 levels of difference: all regions displayed similarity in terms of means (group **a**); all regions to the exclusion of SE and SOUTH had similar means (Tukey group **b**).

pH – 3 levels of difference: three regions, eastNORTH, FUR and KING displayed similar means (Tukey group **a**); regions eastNORTH, NWEST and WEST exhibited similar means (group **b**), while EAST, NWEST, SE, SOUTH and WEST formed group **c**.

EC – 3 levels of difference: regions NWEST and SE displayed similar means (group **a**); all regions with exception of SE and WEST exhibited similar means (Tukey group **b**), and all regions except for EAST, NWEST and SE displayed commonality (group **c**).

Moisture by volume – 2 levels of difference: all regions exhibited similar means (Tukey group **a**), while EAST, eastNORTH, FUR, KING and WEST displayed similar means (**b** group).

Bulk density – 3 levels of difference: regions eastNORTH, FUR, KING and WEST had similar means (Tukey group **a**); EAST, KING, NWEST, and WEST displayed similar means (group **b**), and regions NWEST, SE and EAST exhibited similarity in terms of means (group **c**).

LOI550 – 3 levels of difference: two regions, SE and SOUTH displayed similarities (group **a**); regions EAST, FUR, KING, NWEST and WEST exhibited similarity (Tukey group **b**), while regions eastNORTH, FUR, KING, NWEST and WEST had common means (group **c**).

LOI850 – 3 levels of difference: a reflection of LOI550 (above).

Peat composition – 2 levels of difference: all regions with the exclusion of WEST displayed similar means (Tukey group **a**), while all regions, this time except for SE exhibited similarities (group **b**).

Sand composition – 3 levels of difference: regions eastNORTH, FUR, KING, NWEST and WEST displayed similar means (group **a**); three regions, EAST, NWEST and

SOUTH are similar (group **b**), whereas EAST, SE and SOUTH exhibited similarities (Tukey group **c**).

Loamy-soil composition – 2 levels of difference: all regions were members of Tukey group **a** displaying similar means, and again all regions with the exclusion of EAST and SOUTH formed group **b**.

Summary – Geographic regions HSD test

A clear observation drawn from the geographic regions Tukey groups is that five of the edaphic factors exhibit similar results displaying only two levels of difference, with the remaining six factors displaying three levels. Similar to BOM coastal districts, it is difficult to determine a definitive conclusion in respect to which edaphic factor or factors are suitable indicators of difference between geographic regions, as in all cases difference levels are very low. However, interesting conclusions can be drawn from the Tukey grouping results. In respect of pH, within each of the three Tukey groups, the regions (that make up each Tukey grouping) are geographically contiguous as do those that form the bare ground Tukey groupings. Nonetheless, the remaining factors do not exhibit this type of geographically grouping of regions, many appear as stand-alone with no connection (in the sense of Tuckey groups) to neighbouring regions.

Estuarine groups

The number of plots by soil type by estuarine group (Edgar *et al.* 1999) are presented in Table 4.25. Data in this table is interpreted by column, therefore with a focus on estuarine groups.

Table 4.25: Number and percentage (%) of plots by soil type by estuarine group. Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each estuarine group.

Focus of table is estuarine groups, therefore data is viewed by column.

	Estuarine groups															
Soil type	BLSE		HS_Lag		LMTR		LOMR		Mar_In		MTDRV		Open		Totals	
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	2	5	5	11	4	18	0	0	20	11	2	4	3	6	36	9
2	1	2	5	11	0	0	0	0	24	13	6	12	9	18	45	11
3	5	12	8	17	2	9	0	0	22	12	2	4	4	8	43	11
4	4	10	5	11	6	27	0	0	10	5	2	4	3	6	30	7
5	2	5	6	13	2	9	7	100	27	14	2	4	3	6	49	12
6	8	20	3	7	3	14	0	0	48	25	21	41	20	39	103	25
7	6	15	10	22	4	18	0	0	20	11	6	12	3	6	49	12
8	13	32	4	9	1	5	0	0	18	10	10	20	6	12	52	13
Totals	41	100	46	100	22	100	7	100	189	100	51	100	51	100	407	100

Note: the percent column value is the percentage of plots of the total individual estuarine group within soil type, viewed by column. For example, group **Mar_In** (total 189 plots), **11% of plots are from soil type 1**, **13% from soil type 2**, **22% from soil type 3**, 5% from soil type 4, 14% **from soil type 5**, **25% from soil type 6**, **11% from soil type 7**, and 10% from soil type 8.

Estuarine group codes: **BLSE** = barred, low salinity estuary, **HS_Lag** = hypersaline lagoon, **LMTR** = large meso-tidal river, **LOMR** = large, open micro-tidal river, **Mar_In** = marine inlet, **MTDRV** = micro-tidal drowned river valley, **Open** = open estuary. Terminology follows Edgar (1999).

Five of the seven estuarine groups, BLSE (barred low-salinity estuary), HS_Lag (hyper-saline lagoon), Mar_In (marine inlet), MTDRV (micro-tidal drowned river valley) and Open (open estuary), contain all soil types. The remaining two groups, LMTR (large meso-tidal river) and LOMR (large, open micro-tidal river), contain soil types 7 and 1 respectively. However, it is accepted that the LOMR group recorded a low number of sampled plots, which may suggest why this estuarine group does not display the full range of soil types. It is also possible that this group may have a restricted range of soil types due to their position in the landscape.

The estuarine group of dominance of each soil type is presented in Table 4.26. Data in this table is viewed by row, therefore exhibiting a focus on soil type.

Table 4.26: Number and percentage (%) of plots of each soil type present within each estuarine group. Soil type dominance determined within soil type (not within the estuarine group). Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each soil type.

Focus of table is soil type, therefore data is viewed by row.

Soil type	Estuarine groups														Totals	
	BLSE		HS_Lag		LMTR		LOMR		Mar_In		MTDRV		Open			
	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%	Plots	%
1	2	6	5	14	4	11	0	0	20	56	2	6	3	8	36	100
2	1	2	5	11	0	0	0	0	24	53	6	13	9	20	45	100
3	5	12	8	19	2	5	0	0	22	51	2	5	4	9	43	100
4	4	13	5	17	6	20	0	0	10	33	2	7	3	10	30	100
5	2	4	6	12	2	4	7	14	27	55	2	4	3	6	49	100
6	8	8	3	3	3	3	0	0	48	47	21	20	20	19	103	100
7	6	12	10	20	4	8	0	0	20	41	6	12	3	6	49	100
8	13	25	4	8	1	2	0	0	18	35	10	19	6	12	52	100
Totals	41	10	46	11	22	5	7	2	189	46	51	13	51	13	407	100

Note: the percent column value is the percentage of plots of the total individual soil type within each estuarine group, viewed by row. For example, **soil type 5** (total 49 plots), 4% of plots are in BLSE group, **12% in HS_Lag**, 4% in LMTR, **14% in LOMR**, **55% in Mar_In**, 4% in MTDRV and 6% in Open group.

Estuarine group codes: **BLSE** = barred, low salinity estuary, **HS_Lag** = hypersaline lagoon, **LMTR** = large meso-tidal river, **LOMR** = large, open micro-tidal river, **Mar_In** = marine inlet, **MTDRV** = micro-tidal drowned river valley, **Open** = open estuary. Terminology follows Edgar (1999).

In nearly all cases, individual soil types are not spread across estuarine groups, the exception being soil type 5, which is present in all estuarine groups, though is somewhat limited to low plot numbers in four groups, BLSE, LMTR, MTDRV and Open. The most restricted soil type is group 2, which is not present in estuarine groups LMTR and LOMR, and has a very limited presence in BLSE, being present in just one plot.

Primary soil type dominance (values in **blue**) is totally restricted to one estuarine group, Mar_In, while secondary dominance (value in **red**) is spread among the remaining estuarine groups except for LOMR. The greatest instance of soil types is within the Mar_In group suggesting very high soil type diversity within this estuarine group. As estuarine group classification is landscape focused rather than being geographically focused (as are IBRA, IMCRA, geographic regions and coastal districts), it is difficult to describe how the Mar_In group fits within a geographic sense. Of the total number of plots sampled, 189 (46% of 407 plots) are in the Mar_In group; it can be assumed that members of this group were generally found state-wide.

Individual edaphic factors were aligned to estuarine groups and tested using boxplots and ANOVA.

Estuarine groups edaphic factors boxplots

Similar figure pairs, for LOI, display the same data range to aid better visualisation of results. Observations on Figures 4.84 to 4.94 are provided with Table 4.28 – Tukey groups.

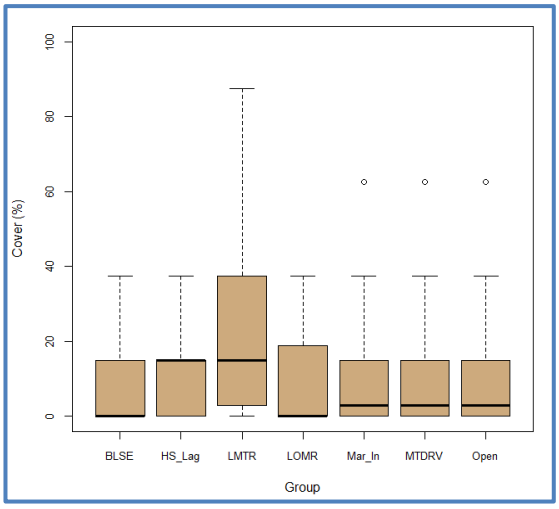


Figure 4.84: Estuarine groups and bare ground.

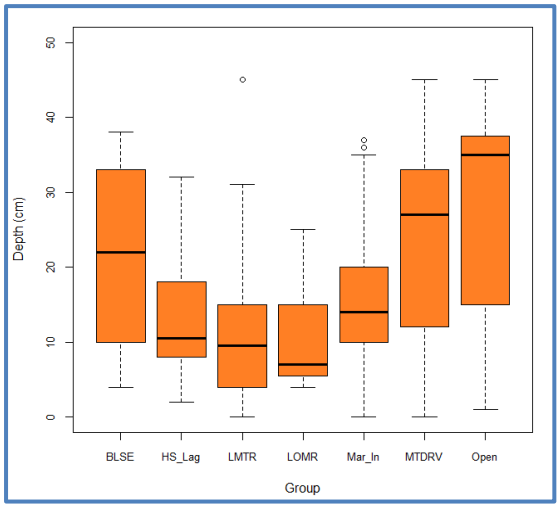


Figure 4.85: Estuarine groups and organic layer depth.

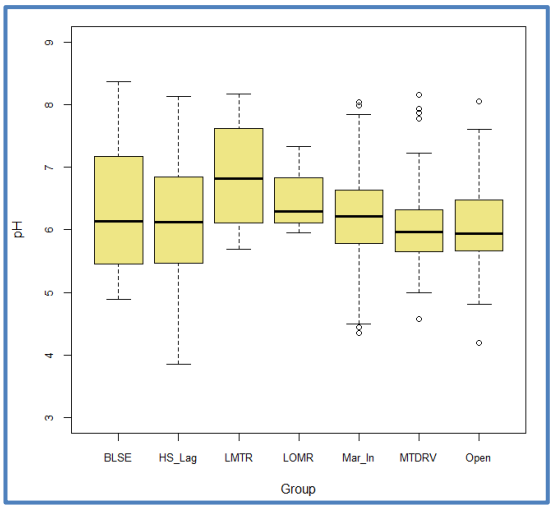


Figure 4.86: Estuarine groups and pH.

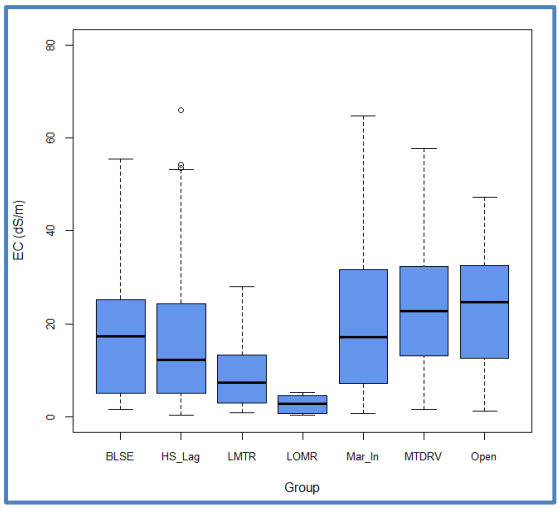


Figure 4.87: Estuarine groups and EC.

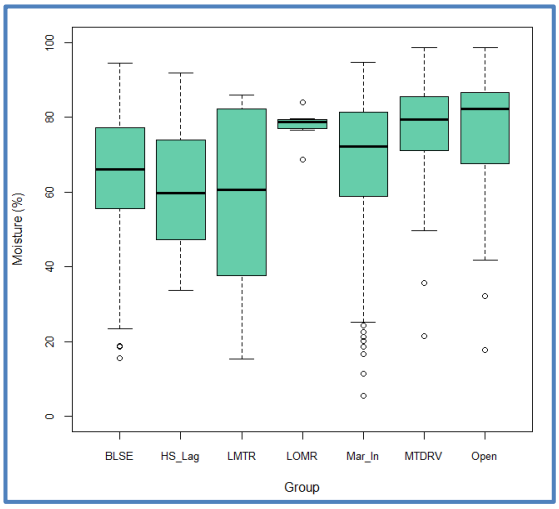


Figure 4.88: Estuarine groups and moisture by volume.

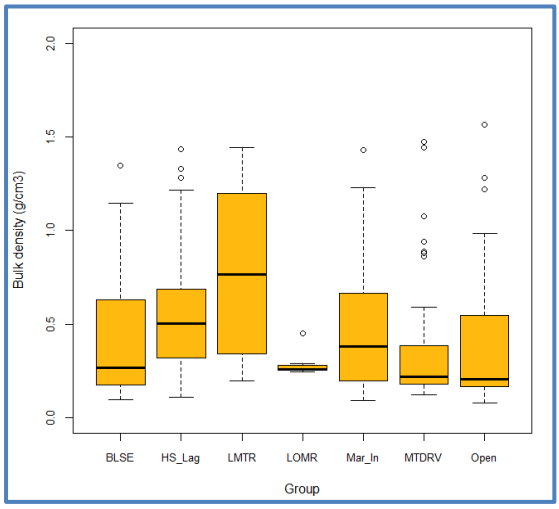


Figure 4.89: Estuarine groups and bulk density.

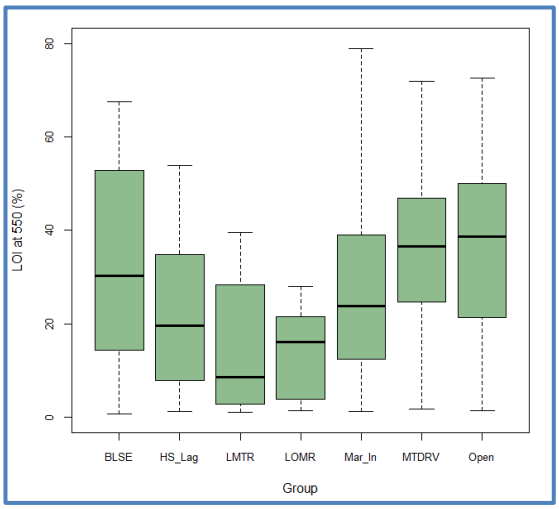


Figure 4.90: Estuarine groups and LOI550.

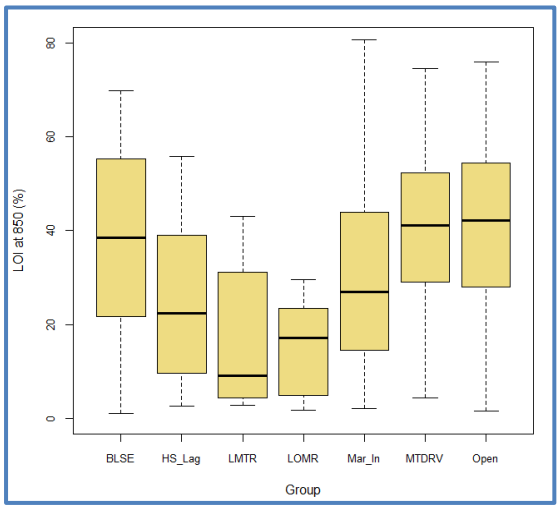


Figure 4.91: Estuarine groups and LOI850.

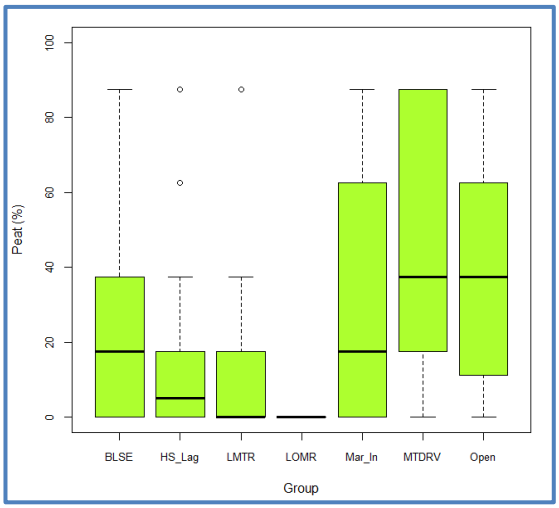


Figure 4.92: Estuarine groups and peat composition.

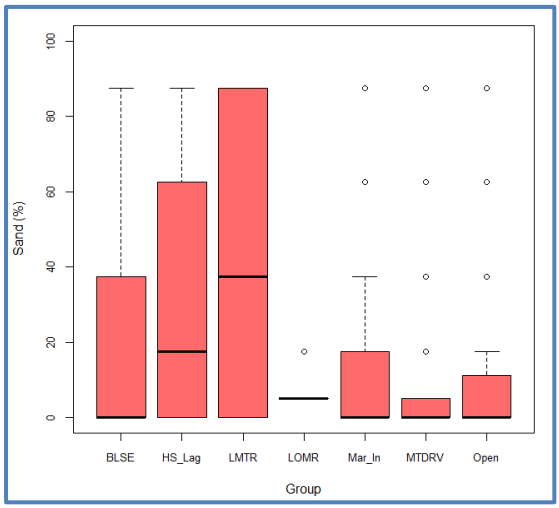


Figure 4.93: Estuarine groups and sand composition.

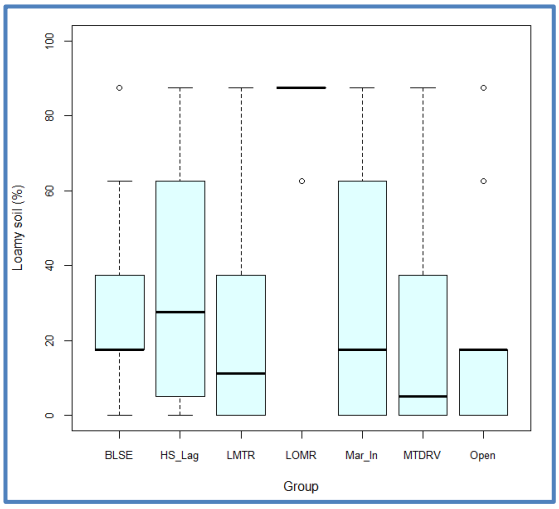


Figure 4.94: Estuarine groups and loamy-soil composition.

Estuarine group codes: **BLSE** = barred, low salinity estuary, **HS_Lag** = hypersaline lagoon, **LMTR** = large meso-tidal river, **LOMR** = large, open micro-tidal river, **Mar_In** = marine inlet, **MTDRV** = micro-tidal drowned river valley, **Open** = open estuary.

Terminology follows Edgar (1999).

Estuarine groups edaphic factors ANOVA

The ANOVA outputs of edaphic factors aligned to estuarine groups are presented in Table 4.27.

Table 4.27: ANOVA results for soil type group edaphic factors aligned to estuarine groups – sorted by order of boxplots.

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	6, 400	2.694	1.42e-02	*
Organic layer depth	Depth	6, 400	14.630	4.05e-15	***
pH	pH	6, 400	2.894	8.98e-03	**
EC (proxy for salinity)	EC	6, 400	4.607	1.54e-04	***
Moisture by volume	M_vol	6, 400	5.904	6.41e-06	***
Bulk density	Bul_den	6, 400	5.773	8.83e-06	***
LOI550	LOI_550	6, 400	7.275	2.17e-07	***
LOI850	LOI_850	6, 400	8.669	6.99e-09	***
Peat composition	Peat	6, 400	6.242	2.77e-06	**
Sand composition	Sand	6, 400	4.171	4.42e-04	***
Loamy-soil composition	L.soil	6, 400	6.869	5.92e-07	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

Many edaphic factors (to the exclusion of bare ground cover, pH and peat composition), have significant differences between estuarine groups. The low p-value ($p<0.001$) indicates that there is at least one group within each edaphic factor that is significantly different to all other estuarine groups within that factor.

Tukey's HSD test results are presented in Table 4.28.

Table 4.28: Estuarine groups means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at p<0.05. Estuarine group order within each edaphic factor is alphabetical.

Estuarine group codes: **BLSE** = barred, low salinity estuary, **HS_Lag** = hypersaline lagoon, **LMTR** = large meso-tidal river, **LOMR** = large, open micro-tidal river, **Mar_In** = marine inlet, **MTDRV** = micro-tidal drowned river valley, **Open** = open estuary. Terminology follows Edgar (1999).

Edaphic factor	Estuarine group	*n*	Mean ± Std error	Min	Max	Tukey group
Bare ground (%)	BLSE	41	9.99 ± 2.18	0.00	37.50	b
	HS_Lag	46	13.50 ± 2.10	0.00	37.50	ab
	LMTR	22	22.32 ± 4.97	0.00	87.50	a
	LOMR	7	10.71 ± 6.92	0.00	37.50	b
	Mar_In	189	11.75 ± 1.07	0.00	62.50	b
	MTDRV	51	9.23 ± 1.98	0.00	62.50	b
	Open	51	8.43 ± 1.77	0.00	62.50	b
Organic layer (cm)	BLSE	41	22.02 ± 1.75	4.00	38.00	a
	HS_Lag	46	12.74 ± 1.05	2.00	32.00	b
	LMTR	22	12.45 ± 2.69	0.00	45.00	b
	LOMR	7	11.00 ± 3.10	4.00	25.00	b
	Mar_In	189	14.72 ± 0.63	0.00	37.00	b
	MTDRV	51	22.98 ± 1.78	0.00	45.00	a
	Open	51	27.35 ± 1.96	1.00	45.00	a
pH	BLSE	41	6.29 ± 0.16	4.89	8.36	ab
	HS_Lag	46	6.29 ± 0.16	3.86	8.13	ab
	LMTR	22	6.87 ± 0.18	5.69	8.17	a
	LOMR	7	6.49 ± 0.20	5.95	7.33	ab
	Mar_In	189	6.22 ± 0.06	4.36	8.04	b
	MTDRV	51	6.07 ± 0.11	4.58	8.15	b
	Open	51	6.08 ± 0.10	4.20	8.05	b
EC (dS/m)	BLSE	41	17.58 ± 2.14	1.65	55.52	ab
	HS_Lag	46	18.33 ± 2.51	0.40	65.90	ab
	LMTR	22	9.75 ± 1.68	0.99	27.93	b
	LOMR	7	2.73 ± 0.81	0.48	5.31	b
	Mar_In	189	21.17 ± 1.19	0.80	64.63	a
	MTDRV	51	23.50 ± 1.88	1.58	57.73	a
	Open	51	23.45 ± 1.87	1.30	47.30	a
Moisture by volume (%)	BLSE	41	63.15 ± 3.20	15.60	94.40	ab
	HS_Lag	46	61.32 ± 2.39	33.66	91.85	ab
	LMTR	22	58.23 ± 4.55	15.29	85.96	ab
	LOMR	7	77.68 ± 1.76	68.57	83.89	a
	Mar_In	189	67.79 ± 1.38	5.54	94.71	ab
	MTDRV	51	75.67 ± 2.09	21.40	98.50	a
	Open	51	75.68 ± 2.47	17.82	98.60	a

Edaphic factor	Estuarine group	*n*	Mean ± Std error	Min	Max	Tukey group
Bulk density (g/cm^3)	BLSE	41	0.43 ± 0.05	0.10	1.35	b
	HS_Lag	46	0.55 ± 0.02	0.11	1.43	ab
	LMTR	22	0.78 ± 0.10	0.20	1.44	a
	LOMR	7	0.29 ± 0.03	0.25	0.45	b
	Mar_In	189	0.48 ± 0.02	0.09	1.43	b
	MTDRV	51	0.36 ± 0.04	0.12	1.47	b
	Open	51	0.38 ± 0.05	0.08	1.56	b
LOI550 (%)	BLSE	41	32.27 ± 3.36	0.81	67.45	ab
	HS_Lag	46	22.01 ± 2.29	1.26	53.90	bc
	LMTR	22	15.23 ± 2.95	1.15	39.49	c
	LOMR	7	13.79 ± 4.02	1.44	28.07	c
	Mar_In	189	26.63 ± 1.27	1.27	78.85	bc
	MTDRV	51	35.64 ± 2.31	1.84	71.88	a
	Open	51	35.29 ± 2.64	1.36	72.56	a
LOI850 (%)	BLSE	41	37.73 ± 3.15	1.17	69.86	ab
	HS_Lag	46	24.61 ± 2.38	2.69	55.80	cd
	LMTR	22	17.36 ± 3.17	2.87	42.99	d
	LOMR	7	15.05 ± 4.20	1.78	29.60	d
	Mar_In	189	29.72 ± 1.35	2.08	80.65	bc
	MTDRV	51	39.54 ± 2.39	4.47	74.56	a
	Open	51	39.59 ± 2.81	1.56	75.82	a
Peat composition (%)	BLSE	41	25.91 ± 4.31	0.00	87.50	bc
	HS_Lag	46	20.71 ± 4.64	0.00	87.50	c
	LMTR	22	14.66 ± 5.78	0.00	87.50	c
	LOMR	7	00.00 ± 0.00	0.00	0.00	c
	Mar_In	189	34.06 ± 2.60	0.00	87.50	abc
	MTDRV	51	47.30 ± 4.50	0.00	87.50	a
	Open	51	44.12 ± 4.64	0.00	87.50	ab
Sand composition (%)	BLSE	41	20.91 ± 5.12	0.00	87.50	ab
	HS_Lag	46	29.24 ± 4.99	0.00	87.50	ab
	LMTR	22	48.68 ± 8.04	0.00	87.50	a
	LOMR	7	6.79 ± 1.79	5.00	17.50	b
	Mar_In	189	17.54 ± 1.94	0.00	87.50	b
	MTDRV	51	12.75 ± 3.58	0.00	87.50	b
	Open	51	13.09 ± 3.80	0.00	87.50	b
Loamy-soil composition (%)	BLSE	41	33.11 ± 4.73	0.00	87.50	b
	HS_Lag	46	33.15 ± 4.45	0.00	87.50	b
	LMTR	22	22.61 ± 5.65	0.00	87.50	b
	LOMR	7	83.93 ± 3.75	62.50	87.50	a
	Mar_In	189	27.51 ± 2.08	0.00	87.50	b
	MTDRV	51	18.82 ± 3.65	0.00	87.50	b
	Open	51	19.46 ± 3.78	0.00	87.50	b

Bare ground – 2 levels of difference: two estuarine groups, HS_Lag and LMTR had similar means (Tukey group **a**), while all estuarine groups, except for LMTR, displayed similarity in terms of means (group **b**).

Organic layer depth – 2 levels of difference: three estuarine groups, BLSE, MTDRV and Open, displayed commonality in terms of means (group **a**), whereas the remaining four groups recorded similar means (Tukey group **b**).

pH – 2 levels of difference: groups BLSE, HS_Lag, LMTR and LOMR were similar in terms of means (Tukey group **a**), while all estuarine groups, apart from LMTR, displayed common means (group **b**).

EC – 2 levels of difference: all groups except for LMTR and LOMR exhibited similar means (group **a**); four estuarine groups, BLSE, HS_Lag, LMTR and LOMR recorded commonality (Tukey group **b**).

Moisture by volume – 2 levels of difference: all estuarine groups were similar (Tukey group **a**), whereas, BLSE, HS_Lag, LMTR and Mar_In displayed similarity (group **b**).

Bulk density – 2 levels of difference: two groups, HS_Lag and LMTR displayed similarity (group **a**), and all estuarine groups, apart from LMTR, had similar means (Tukey group **b**).

LOI550 – 3 levels of difference: three estuarine groups, BLSE, MTDRV and Open had similar means (Tukey group **a**); BLSE, HS_Lag and Mar_In displayed similarity in terms of means (group **b**), while HS_Lag, LMTR, LOMR and Mar_In recorded common means (group **c**).

LOI850 – 4 levels of difference: estuarine groups, BLSE, MTDRV and Open had similar means (group **a**); BLSE and Mar_In displayed commonality (Tukey group **b**); HS_Lag and Mar_In make up group **c**, whereas, HS_Lag, LMTR and LOMR had common means (group **d**).

Peat composition – 3 levels of difference: three estuarine groups displayed means similarity, Mar_In, MTDRV and Open (group **a**); groups, BLSE, Mar_In and Open

were similar in terms of means (group **b**), and BLSE, HS_Lag, LMTR, LOMR and Mar_In made up Tukey group **c**.

Sand composition – 2 levels of difference: estuarine groups BLSE, HS_Lag and LMTR exhibited similarity in means (Tukey group **a**); all estuarine groups with exception of LMTR displayed common means (group **b**).

Loamy-soil composition – 2 levels of difference: LOMR was the sole member of Tukey group **a**, while all other estuarine groups displayed similar means and make up group **b**.

Summary – Estuarine classification groups HSD test

Interestingly, eight of the eleven estuarine classification edaphic factors have only two levels of difference, while two, LOI550 and peat composition have three levels, and the final factor, LOI850 has four levels of difference. As the estuarine classification has been completed on nine physical characteristics, one would have expected there to be a greater level of difference within edaphic factors. In this case, estuarine groups have the poorest degree of separation within factors, thus suggesting that this classification type is unsuitable in defining soil types of coastal saltmarshes. It is accepted that only one characteristic used to determine estuarine classification, salinity of surface water, may have a direct bearing on any edaphic factor, in this case, EC.

Review – edaphic factors and regionalisation

The following section focuses on regionalisation and edaphic factors. Note: here the terms "regionalisation" (IBRA, IMCRA etc.), "districts" (BOM coastal) and "classification" (estuarine) are generally included under the single term "regionalisation", while the terms "region", "district" and "group" (sub forms of regionalisation etc.) are incorporated under the term "region".

F value results

The F value from the individual ANOVA outputs of edaphic factors aligned to regionalisations are presented in Table 4.29. The F value (the greater the value, the greater the significant difference between means) has been used as the responsible test statistic in determining which type of regionalisation best captures the diversity of edaphic factors.

Table 4.29: ANOVA F value results for soil type edaphic factors aligned to each regionalisation type assessed above – sorted by standard used previously. The highest F value for each edaphic factor across the five regionalisation types is highlighted in **blue**, second highest value highlighted in **red**, the third highest highlighted in **green**. The results below have been sourced from Tables 4.11, 4.15, 4.19, 4.23 and 4.27.

Focus of table is each edaphic factor (comparing each regionalisation type), therefore data is viewed by row.

	Regionalisation type				
Edaphic factor	**IBRA**	**IMCRA**	**Coastal**	**Geographic**	**Estuarine**
Bare ground	**7.226**	**7.387**	6.183	**6.540**	2.694
Organic layer depth	**7.431**	**9.514**	3.378	4.679	**14.630**
pH	**7.429**	**11.870**	3.991	**10.770**	2.894
EC	**11.820**	**9.342**	7.042	**8.229**	4.607
Moisture by volume	5.284	**6.811**	3.084	**6.455**	**5.904**
Bulk density	**10.390**	**12.800**	6.866	**12.530**	5.773
LOI550	**13.340**	**14.520**	9.897	**12.450**	7.275
LOI850	**12.360**	**13.800**	9.285	**11.830**	8.669
Peat composition	**7.324**	3.337	**4.761**	3.179	**6.242**
Sand comp	**20.670**	**16.600**	10.38	**15.830**	4.171
Loam soil comp	1.580	**4.178**	3.952	**5.324**	**6.869**

Note: the columns are compared between all regionalisation types across each edaphic factor, therefore viewed by row. For example, **LOI550**, the highest F value is **14.520** (IMCRA), the second highest **13.340** (IBRA), and the third highest **12.450** (Geographic).

The two regionalisations that display the highest and second highest F values were IBRA and IMCRA. To determine the regionalisation that best represents the individual factor, the highest F value within each edaphic factor across the regionalisations attracts a ranking value of 10 points, the second highest 5 points, while the third highest attracts 2.5 points. The total points by each regionalisation determines which best represents the diversity of soil types (Table 4.30).

Table 4.30: Regionalisation types, number of regions within each type, ANOVA F value rankings. Value in parenthesis is the ranking value, where the highest ranking is valued at 10 points, the second highest ranking is valued at 5 points and the third highest valued at 2.5 points. Regionalisation order is presented by rank.

Regionalisation	**Regions**	**Highest**	**2nd Highest**	**3rd highest**	**Ranking points**	**Rank**
IMCRA	7	**6 (60)**	**3 (15)**	**1 (2.5)**	77.5	1
IBRA	6	**3 (30)**	**3 (15)**	**3 (7.5)**	47.5	2
Geographic	8	**0**	**4 (20)**	**5 (12.5)**	32.5	3
Estuarine	7	**2 (20)**	**1 (5)**	**1 (2.5)**	27.5	4
BOM coastal	10	**0**	**0**	**1 (2.5)**	2.5	5

From Table 4.30, IMCRA has the best in terms of F values (6 highest, 3 second highest and 1 third highest), with the next best option being IBRA (3 highest, 3 second highest and 3 third highest). When a ranking value is applied, IMCRA regionalisation is positioned as the best "indicator" in terms of significant differences (F value) between regions, followed by IBRA, geographic, estuarine and finally BOM coastal. This result is interesting as it appears that the number of regions within the regionalisation had some influence on the result. The lowest ranked, BOM coastal has 10 districts, whereas the highest ranked, IMCRA has 7 regions, only one greater than IBRA which was the second highest ranked regionalisation. This implies that a smaller number of regions within a regionalisation provides a better option in assigning soil type groups, perhaps as each region has a greater "spread".

Tukey HSD groups

Similar to F value analysis above, Tukey groups levels of difference were aligned to regionalisations and are presented in Table 4.31. The levels of difference have been used as this highlights the greater number of significant differences between groups within each edaphic factor.

Table 4.31: Tukey HSD grouping results for level(s) of difference for soil type edaphic factors aligned to each regionalisation type assessed above – sorted by standard used previously. The greatest number for each edaphic factor across the five regionalisation types is highlighted in **blue**, where the levels of difference are equal across all regionalisations, no type has been attributed as best. The data below have been sourced from Tables 4.12, 4.16, 4.20, 4.24 and 4.28 (Tukey HSD results).

Focus of table is each edaphic factor (comparing each regionalisation type), therefore data is viewed by row.

	Regionalisation				
Edaphic factor	**IBRA**	**IMCRA**	**Coastal**	**Geographic**	**Estuarine**
Bare ground	2	2	2	2	2
Organic layer depth	2	2	2	2	2
pH	2	**4**	2	3	2
EC	**4**	3	2	3	2
Moisture by volume	2	**3**	2	2	2
Bulk density	2	**3**	2	**3**	2
LOI550	**3**	**3**	2	**3**	**3**
LOI850	3	3	2	3	**4**
Peat composition	**3**	2	2	2	**3**
Sand comp	2	2	**3**	**3**	2
Loam soil comp	0	**2**	**2**	**2**	**2**

Note: the columns are compared between all regionalisation types across each edaphic factor, therefore viewed by row. For example, **LOI550**, the greatest level of difference is **3 for each of** IBRA, IMCRA and Geographic.

IMCRA displays the greatest levels of difference over five edaphic factors, however, three are shared with other regionalisation types. To determine the regionalisation that best represents levels of difference, two methods were considered: a) the number of greatest levels of difference, and b) the total of levels of difference for each regionalisation (Table 4.32).

Table 4.32: Regionalisation types, number of regions within each type, the number of greatest levels of difference and ranking, the total number of levels of difference and ranking. Regionalisation order is presented by rank.

		Greatest levels of difference		Total levels of difference	
Regionalisation	**Regions**	**Number**	**Rank**	**Number**	**Rank**
IMCRA	7	5	1	29	1
Geographic	8	4	2	28	2
Estuarine	7	4	2	26	3
IBRA	6	3	4	25	4
BOM coastal	10	2	5	23	5

Again, IMCRA most highly in terms of Tukey HSD greatest levels of difference and total levels of difference, with the next best option being Geographic, followed by estuarine, IBRA and BOM coastal. Considering the analyses presented above (Tables 4.29 to 4.31), IMCRA regions align best with soil type patterning and are therefore considered suitable candidates to regionalise Tasmanian coastal saltmarsh soil types.

4.4.7 Vegetation communities

This section only examines and reviews edaphic factors and vegetation communities, it does not consider edaphic factors and individual plant species. This is addressed in Chapter 6.

The number of plots by soil type by vegetation community are presented in Table 4.33. Data in this table is interpreted by column, therefore exhibiting a focus on vegetation communities.

Table 4.33: Number of plots and percentage (%) by soil type by vegetation community. Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each vegetation community.

Focus of table is vegetation communities, therefore data is viewed by column.

	Vegetation community																	
Soil type	**AGH**		**AHM**		**AHR**		**AJK**		**AQR**		**ARH**		**ASH**		**ASQ**		**Totals**	
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	**17**	**26**	5	8	2	6	1	3	0	0	5	9	1	2	5	6	36	9
2	3	5	**7**	**11**	**5**	**15**	1	3	**2**	**11**	3	5	**5**	**10**	**19**	**22**	**45**	**11**
3	3	5	**9**	**14**	3	9	**6**	**17**	1	6	4	7	**7**	**14**	**10**	**12**	**43**	**11**
4	**5**	**8**	5	8	1	3	3	8	**2**	**11**	3	5	1	2	**10**	**12**	30	7
5	**17**	**26**	**11**	**17**	3	9	3	8	0	0	**6**	**11**	**6**	**12**	3	4	**49**	**12**
6	**6**	**9**	**19**	**30**	**8**	**24**	**10**	**28**	**9**	**50**	**12**	**21**	**14**	**29**	**25**	**29**	**103**	**25**
7	4	6	2	3	**4**	**12**	3	8	**4**	**22**	**7**	**12**	**14**	**29**	**11**	**13**	**49**	**12**
8	**11**	**17**	5	8	**7**	**21**	**9**	**25**	0	0	**17**	**30**	1	2	2	2	**52**	**13**
Totals	66	100	63	100	33	100	36	100	18	100	57	100	49	100	85	100	407	100

Note: the percent column value is the percentage of plots of the total individual vegetation community within soil type, viewed by column.

For example, **vegetation community AHR** (total 33 plots), 6% of plots are from soil type 1, **15% from soil type 2**, 9% from soil type 3, 3% from soil type 4, 9% from soil type 5, **24% from soil type 6**, 12% from soil type 7, and **21% from soil type 8**.

Vegetation community codes: **AGH** = saline graminoids, **AHM** = mixed herbs, **AHR** = herbs and rushes, **AJK** = *Juncus kraussii*, **AQR** = *S. quinqueflora* and *S. repens*, **ARH** = rushes and herbs, **ASH** = shrubs and herbs, **ASQ** = *Sarcocornia quinqueflora*.

All vegetation communities, except for AQR *(S. quinqueflora/S. repens),* contain all soil types; AQR is not exhibited in soil types 1, 5 and 8. However, two vegetation communities, AHR (herbs and rushes) and ASH (shrubs and herbs), record in two instances just one plot in soil type 4, with ASH also recording a single plot in soil type 1. Additionally, both AHR and ASH record 8 and 4 percent (respectively) of the total plots, which may suggest as to why these regions have a low diversity of soil types. The initial interpretation of the above results proposes that vegetation community presence is not entirely determined by soil type, nor do vegetation communities determine soil type.

However, closer inspection of the data reveals that that vegetation community AGH (graminoids and herbs) prefers soil types 1 and 5, communities AHM (herbs mixed), AHR, AJK *(J. kraussii),* AQR and ASQ *(S. quinqueflora)* prefer soil type 6, ARH (rushes and herbs) favours soil type 8, while vegetation community ASH prefers soil types 6 and 7. However, this could not be considered a firm proposal, as in several cases (AHR, AJK and AQR) the percentage of sampled plots within some soil types is too low.

The vegetation community of dominance by each soil type is presented in Table 4.34. Data in this table is viewed by row, therefore exhibiting a focus on soil type.

Table 4.34: Number and percentage (%) of plots of each soil type present within each vegetation community. Soil type dominance determined within soil type (not within the community). Values (number of plots and percentage) in **blue** are highest, those in **red** are middle of range, and those in **green** are lowest (generally <10% excluded) within each soil type.

Focus of table is soil type, therefore data is viewed by row.

Soil type	Vegetation community																Totals	
	AGH		AHM		AHR		AJK		AQR		ARH		ASH		ASQ			
	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%	Plot	%
1	**17**	**47**	**5**	**14**	2	6	1	3	0	0	**5**	**14**	1	3	**5**	**14**	36	100
2	3	7	**7**	**16**	**5**	**11**	1	2	2	4	3	7	**5**	**11**	**19**	**42**	45	100
3	3	7	**9**	**21**	3	7	**6**	**14**	1	2	4	9	**7**	**16**	**10**	**23**	43	100
4	**5**	**17**	**5**	**17**	1	3	**3**	**10**	2	7	**3**	**10**	1	3	**10**	**33**	30	100
5	**17**	**35**	**11**	**22**	3	6	3	6	0	0	**6**	**12**	**6**	**12**	3	6	49	100
6	6	6	**19**	**18**	8	8	**10**	**10**	9	9	**12**	**12**	**14**	**14**	**25**	**24**	103	100
7	4	8	2	4	4	8	3	6	4	8	**7**	**14**	**14**	**29**	**11**	**22**	49	100
8	**11**	**21**	5	10	**7**	**13**	**9**	**17**	0	0	**17**	**33**	1	2	2	4	52	100
Totals	**66**	**16**	**63**	**15**	33	8	36	9	18	4	**57**	**14**	**49**	**12**	**85**	**21**	407	100

Note: the percent column value is the percentage of plots of the total individual soil type within each vegetation community, viewed by row.

For example, **soil type 5** (total 49 plots), **35% of plots are in AGH community**, **22% in AHM**, 6% in AHR, 6% in AJK, 0% in AQR, **12% in ARH**, **12% in ASH**, and 6% in ASQ.

Vegetation community codes: **AGH** = saline graminoids, **AHM** = mixed herbs, **AHR** = herbs and rushes, **AJK** = *Juncus kraussii*, **AQR** = *S. quinqueflora* and *S. repens*, **ARH** = rushes and herbs, **ASH** = shrubs and herbs, **ASQ** = *Sarcocornia quinqueflora*.

In many cases, individual soil types are spread across all vegetation communities, the exceptions being soil types 1, 5 and 8, all absent in community AQR. Generally, soil types are evenly spread between vegetation communities, suggesting that most communities are tolerant of various soil types. Four soil types, 2, 3, 4 and 6, display dominancy (see values in **blue**) within community ASQ, while soil types 1 and 5 display dominancy in community AGH. Vegetation community AHM is well tolerant of many soil types, soil type 3 displays dominancy (as well as in ASQ) and secondary dominancy is well displayed from soil types 2, 4, 5 and 6 (see values in **red**).

It would have been expected that vegetation communities are a response to soil type, that is, plant species presence/absence is impacted by certain edaphic factors (e.g. pH or EC). However, this is not strictly evident as most vegetation communities are found across all soil types. From this, it could be concluded that either, a combination of edaphic factors (e.g. pH, moisture and composition together) play a more prevailing role in vegetation community presence (rather than individual factors), or, that vegetation communities do not determine soil type, thus suggesting that saltmarsh plant species are generally efficient at adapting to, or more tolerant of, various soil types. This appears certainly to be the case when vegetation communities are considered an association of plant species. Thus, individual species appearing associated with certain other species, may have a greater tolerance to an extended range of an edaphic factor, rather than if appearing as an individual. It is accepted that other factors can impact vegetation community presence (e.g. marine water inundation, duration), however, these factors were not assessed during this study.

Individual edaphic factors were aligned to individual vegetation groups (those determined in Chapter 3) and tested using boxplots and ANOVA.

Vegetation community edaphic factors boxplots

Similar figure pairs, (e.g. LOI), display the same data range to aid better visualisation of results. Observations on Figures 4.95 to 4.105 are provided with Table 4.36 – Tukey groups. Boxplot data – minimums, 1st, 2nd, 3rd quartiles and maximums are provided in Appendix 4A.3.

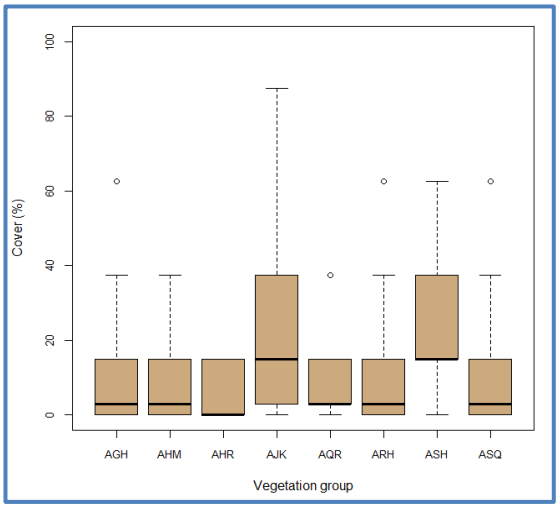


Figure 4.95: Vegetation groups and bare ground.

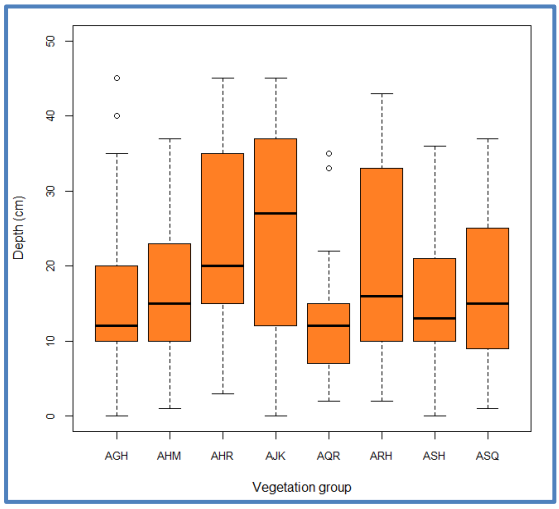


Figure 4.96: Vegetation groups and organic layer depth.

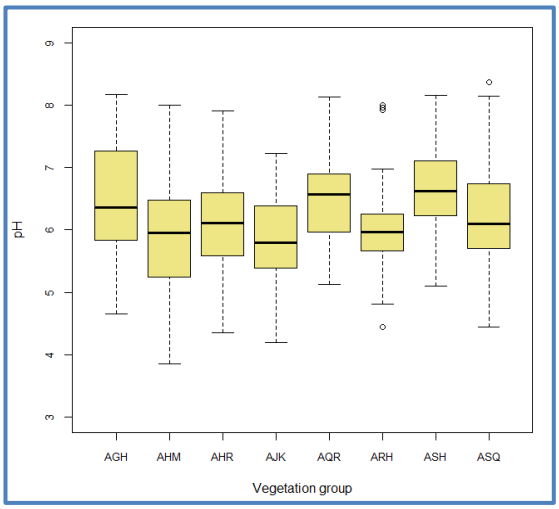


Figure 4.97: Vegetation groups and pH.

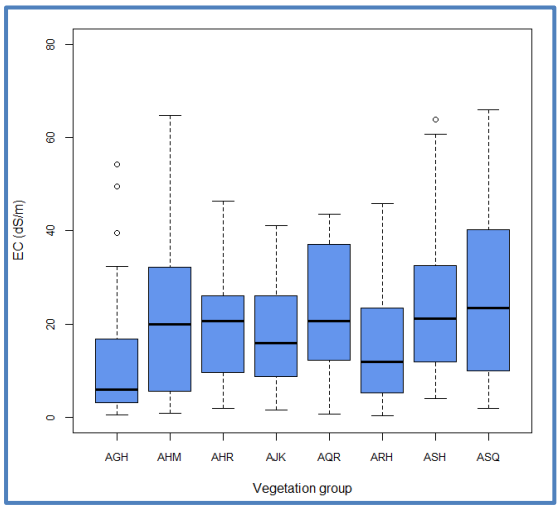


Figure 4.98: Vegetation groups and EC.

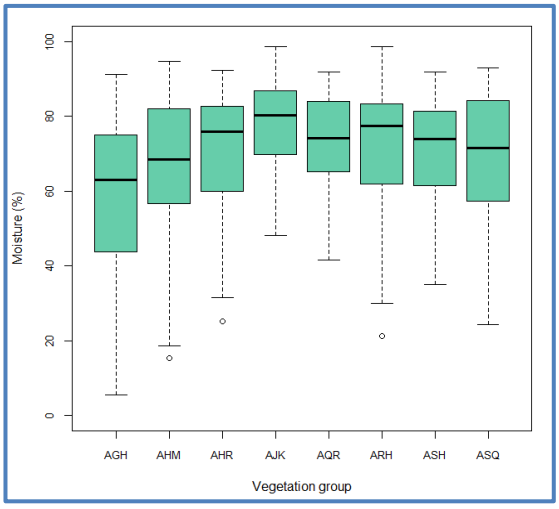


Figure 4.99: Vegetation groups and moisture by volume.

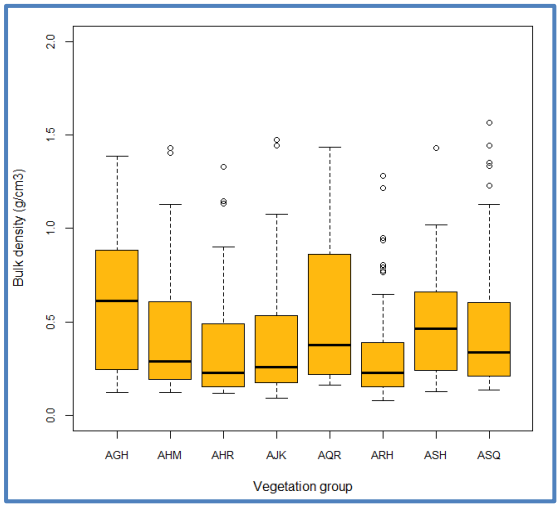


Figure 4.100: Vegetation groups and bulk density.

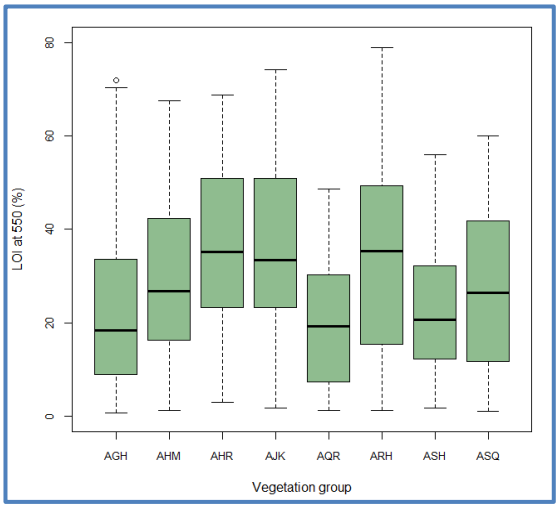


Figure 4.101: Vegetation groups and LOI550.

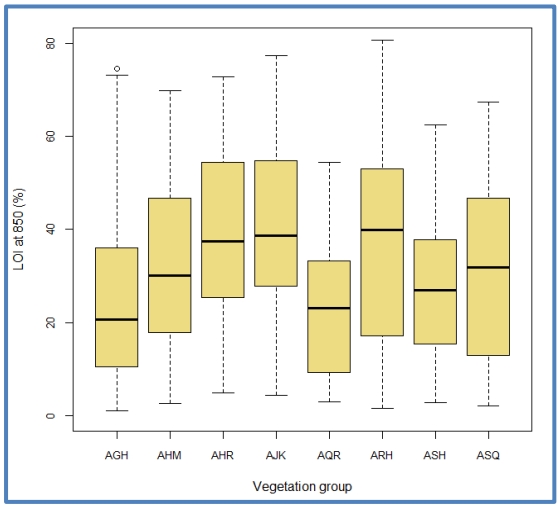


Figure 4.102: Vegetation groups and LOI850.

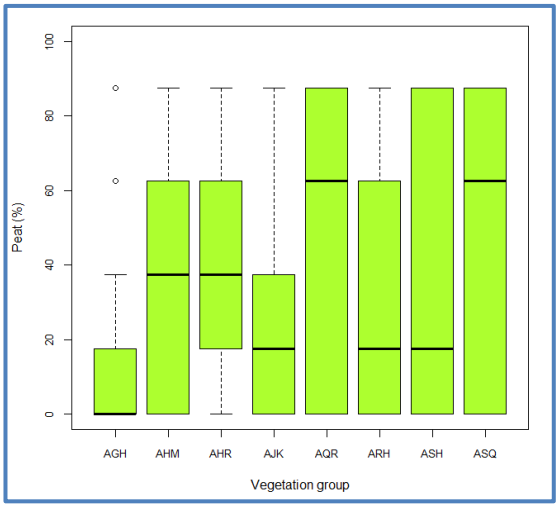


Figure 4.103: Vegetation groups and peat composition.

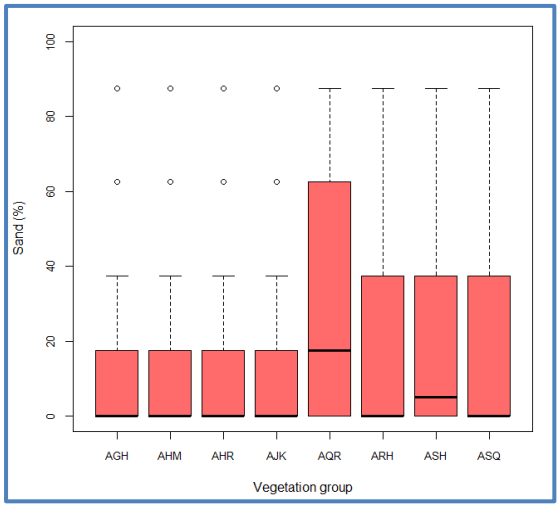


Figure 4.104: Vegetation groups and sand composition.

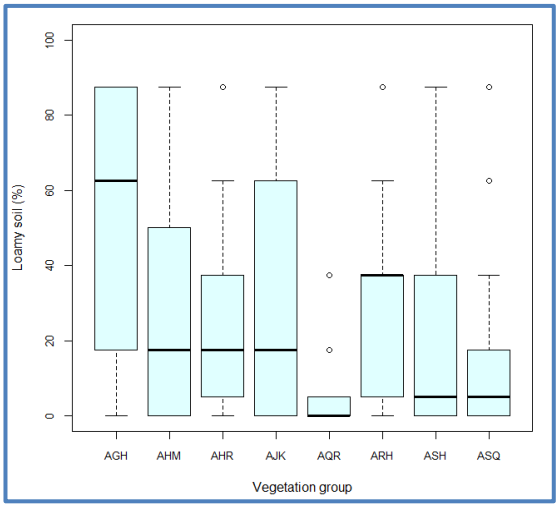


Figure 4.105: Vegetation groups and loamy-soil composition.

Vegetation community codes:
AGH = saline graminoids, **AHM** = mixed herbs, **AHR** = herbs and rushes, **AJK** = *Juncus kraussii*, **AQR** = *S. quinqueflora* and *S. repens*, **ARH** = rushes and herbs, **ASH** = shrubs and herbs, **ASQ** = *Sarcocornia quinqueflora*.

Vegetation communities' edaphic factors ANOVA

The ANOVA outputs of vegetation group edaphic factors are presented in Table 4.35.

Table 4.35: ANOVA results for vegetation group edaphic factors – sorted by order of boxplots.

Edaphic factor	Code	Df	F value	p-value	
Bare ground	Bar_grd	7, 399	8.760	5.00e-10	***
Organic layer depth	Depth	7, 399	5.165	1.21e-05	***
pH	pH	7, 399	6.371	4.09e-07	***
EC (proxy for salinity)	EC	7, 399	6.923	8.67e-08	***
Moisture by volume	M_vol	7, 399	5.703	6.67e-06	***
Bulk density	Bul_den	7, 399	3.037	1.97e-03	**
LOI550	LOI_550	7, 399	4.258	1.49e-04	***
LOI850	LOI_850	7, 399	3.735	6.23e-04	***
Peat composition	Peat	7, 399	5.529	4.36e-06	***
Sand composition	Sand	7, 399	1.384	2.10e-01	
Loamy-soil composition	L.soil	7, 399	11.250	5.00e-13	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

All edaphic factors except for sand composition display significant differences between vegetation groups. The low p-value ($p<0.001$) for each indicates that there is at least one vegetation group within each edaphic factor (excluding sand composition) that is significantly different to all other vegetation groups within that factor.

Tukey's HSD test results are presented in Table 4.36.

Table 4.36: Vegetation group means, standard error, range (minimum to maximum) and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter (Tukey groups) are not different at $p<0.05$. Vegetation group order within each edaphic factor is alphabetical.

Vegetation community codes: **AGH** = saline graminoids and herbs, **AHM** = mixed herbs, **AHR** = herbs and rushes, **AJK** = *Juncus kraussii*, **AQR** = *S. quinqueflora* and *S. repens*, **ARH** = rushes and herbs, **ASH** = shrubs and herbs, **ASQ** = *Sarcocornia quinqueflora*.

Edaphic factor	Veg group	*n*	Mean ± Std Error	Min	Max	Tukey group
Bare ground (%)	AGH	66	10.48 ± 1.77	0.00	62.50	bc
	AHM	63	9.29 ± 1.58	0.00	37.50	c
	AHR	33	4.91 ± 1.19	0.00	15.00	c
	AJK	36	19.07 ± 3.56	0.00	87.50	ab
	AQR	18	11.58 ± 3.13	0.00	37.50	bc
	ARH	57	8.41 ± 1.94	0.00	62.50	c
	ASH	49	23.71 ± 2.10	0.00	62.50	a
	ASQ	85	8.73 ± 1.43	0.00	62.50	c

Edaphic factor	Veg group	*n*	Mean ± Std Error	Min	Max	Tukey group
Organic layer (cm)	AGH	66	15.79 ± 1.22	0.00	45.00	c
	AHM	63	16.70 ± 1.22	1.00	37.00	bc
	AHR	33	23.70 ± 2.14	3.00	45.00	ab
	AJK	36	24.94 ± 2.41	0.00	45.00	a
	AQR	18	12.94 ± 2.15	2.00	35.00	c
	ARH	57	20.75 ± 1.64	2.00	43.00	abc
	ASH	49	16.14 ± 1.36	0.00	36.00	c
	ASQ	85	17.07 ± 1.14	1.00	37.00	bc
pH	AGH	66	6.47 ± 0.11	4.66	8.17	ab
	AHM	63	5.94 ± 0.11	3.86	8.00	b
	AHR	33	6.18 ± 0.15	4.36	7.90	b
	AJK	36	5.88 ± 0.11	4.20	7.22	b
	AQR	18	6.52 ± 0.17	5.13	8.13	ab
	ARH	57	6.02 ± 0.09	4.45	8.00	b
	ASH	49	6.72 ± 0.10	5.10	8.15	a
	ASQ	85	6.27 ± 0.10	4.45	8.36	b
EC (dS/m)	AGH	66	11.46 ± 1.48	0.54	54.15	c
	AHM	63	22.26 ± 2.13	0.99	64.63	abc
	AHR	33	20.03 ± 2.17	1.95	46.37	abc
	AJK	36	18.08 ± 2.00	1.58	41.05	abc
	AQR	18	22.34 ± 3.20	0.79	43.65	abc
	ARH	57	15.90 ± 1.66	0.40	45.85	bc
	ASH	49	24.07 ± 2.20	4.11	63.77	ab
	ASQ	85	26.28 ± 1.90	1.89	65.90	a
Moisture by volume (%)	AGH	66	57.45 ± 2.77	5.54	91.26	c
	AHM	63	65.71 ± 2.58	15.29	94.71	bc
	AHR	33	70.66 ± 3.06	25.22	92.35	abc
	AJK	36	78.10 ± 2.26	48.07	98.60	a
	AQR	18	71.51 ± 3.47	41.55	91.89	abc
	ARH	57	71.52 ± 2.27	21.27	98.50	ab
	ASH	49	71.63 ± 1.94	34.94	91.71	ab
	ASQ	85	68.44 ± 1.95	24.20	92.88	abc
Bulk density (g/cm^3)	AGH	66	0.61 ± 0.04	0.12	1.39	a
	AHM	63	0.45 ± 0.04	0.12	1.43	ab
	AHR	33	0.40 ± 0.06	0.12	1.33	ab
	AJK	36	0.39 ± 0.06	0.09	1.47	b
	AQR	18	0.53 ± 0.09	0.17	1.43	ab
	ARH	57	0.36 ± 0.04	0.08	1.28	b
	ASH	49	0.49 ± 0.04	0.13	1.43	ab
	ASQ	85	0.47 ± 0.04	0.14	1.56	ab

Edaphic factor	Veg group	*n*	Mean ± Std Error	Min	Max	Tukey group
LOI550 (%)	AGH	66	22.68 ± 2.23	0.81	71.88	b
	AHM	63	28.93 ± 2.16	1.19	67.45	ab
	AHR	33	35.24 ± 3.39	3.06	68.77	a
	AJK	36	35.01 ± 3.30	1.84	74.09	a
	AQR	18	21.12 ± 3.51	1.35	48.64	b
	ARH	57	33.34 ± 2.75	1.26	78.85	a
	ASH	49	22.44 ± 2.01	1.77	55.98	b
	ASQ	85	27.01 ± 1.85	1.15	60.08	ab
LOI850 (%)	AGH	66	25.24 ± 2.31	1.17	74.56	b
	AHM	63	32.07 ± 2.25	2.69	69.72	ab
	AHR	33	38.35 ± 3.49	4.95	72.79	a
	AJK	36	38.44 ± 3.42	4.46	77.21	a
	AQR	18	24.79 ± 3.80	2.95	54.37	b
	ARH	57	36.38 ± 2.84	1.56	80.65	a
	ASH	49	26.57 ± 2.25	2.76	62.47	ab
	ASQ	85	31.31 ± 2.00	2.08	67.33	ab
Peat composition (%)	AGH	66	14.89 ± 3.26	0.00	87.50	b
	AHM	63	36.35 ± 4.49	0.00	87.50	a
	AHR	33	40.83 ± 5.73	0.00	87.50	a
	AJK	36	23.82 ± 4.48	0.00	87.50	ab
	AQR	18	45.69 ± 8.53	0.00	87.50	a
	ARH	57	28.77 ± 3.95	0.00	87.50	ab
	ASH	49	35.51 ± 5.15	0.00	87.50	a
	ASQ	85	44.21 ± 4.06	0.00	87.50	a
Sand composition (%)	AGH	66	18.18 ± 3.53	0.00	87.50	a
	AHM	63	16.39 ± 3.32	0.00	87.50	a
	AHR	33	12.80 ± 4.40	0.00	87.50	a
	AJK	36	12.92 ± 4.35	0.00	87.50	a
	AQR	18	32.50 ± 8.64	0.00	87.50	a
	ARH	57	18.03 ± 3.63	0.00	87.50	a
	ASH	49	22.40 ± 4.00	0.00	87.50	a
	ASQ	85	22.91 ± 3.69	0.00	87.50	a
Loamy-soil composition (%)	AGH	66	48.30 ± 3.98	0.00	87.50	a
	AHM	63	29.13 ± 3.84	0.00	87.50	b
	AHR	33	27.05 ± 4.48	0.00	87.50	bc
	AJK	36	30.07 ± 5.16	0.00	87.50	b
	AQR	18	6.94 ± 2.93	0.00	37.50	c
	ARH	57	32.76 ± 3.79	0.00	87.50	b
	ASH	49	20.36 ± 3.61	0.00	87.50	bc
	ASQ	85	13.32 ± 2.15	0.00	87.50	c

Bare ground – 3 levels of difference: vegetation communities AJK and ASH displayed similar means (Tukey group **a**); AGH, AJK and AQR shared commonality through means (group **b**), and all communities, except for AJK and ASH, exhibited similarity in terms of means (group **c**).

Mean bare ground values differed nearly four-fold between vegetation communities ARH (8.41 ± 1.94) and ASH (23.71 ± 2.10). The largest range of bare ground was observed in community AJK (0.0-87.5, 87.5), whereas the smallest range was found in AHR (0.0-15.0, 15.0). All vegetation communities recorded the minimum (0.0) in bare ground, while community AJK recorded the maximum (87.5).

Organic layer depth – 3 levels of difference: communities AJK and ARH were similar in terms of means (group **a**); AHM, AHR, ARH and ASQ exhibited commonality (Tukey group **b**), whereas all vegetation communities, except for AHR and AJK, recorded similar means (group **c**).

Organic layer means varied approximately two-fold; community AQR (12.94 ± 2.15) to AJK (24.94 ± 2.41). The lowest range/spread was also recorded by community AQR (2.0-35.0, 33.0), with communities AGH and AJK both exhibiting the greatest range/spread of organic depth (0.0-45.0, 45.0). Communities AGH, AJK and ASH all displayed the shallowest depth (0.0), while communities AGH, AHR and AJK each recorded the deepest measure of organic layer (45.0).

pH – 2 levels of difference: three vegetation communities, AGH, AQR and ASH, displayed similar means (Tukey group **a**), and all communities, apart from ASH, shared commonality in terms of means (group **b**).

Means of pH differed nearly one pH unit with AJK recording a mean of 5.88 ± 0.11 to that of ASH at 6.72 ± 0.10. The greatest range/spread in pH was observed in community AHM (3.86-8.00, 4.14), while the lowest was found in AJK and AQR (4.20-7.22, 3.02 and 5.13-8.13, 3.00 respectively). The most acidic record was noted in community AHM (3.86), whereas the most alkaline value was observed in ASQ (8.36). All vegetation communities' pH ranges incorporated both acidic (<7.0) and alkaline (>7.0) values.

EC – 3 levels of difference: communities AHM, AHR, AJK, AQR, and ASH recorded similar means (group **a**); all vegetation communities, excluding AGH and ASQ, made up Tukey group **b**, while all communities, except for ASH and ASQ, displayed similar means (group **c**).

Variation in EC means differed over two-fold between AGH (11.46 ± 1.48) and ASQ (26.28 ± 1.90). The smallest EC range/spread was observed in AJK (1.58-41.05, 39.47), whereas ASQ recorded the greatest (1.89-65.90, 64.01), followed by AHM (0.99-64.63, 63.64). The lowest EC observation was found in ARH (0.40), while the highest was observed in ASQ (65.90).

Moisture by volume – 3 levels of difference: all vegetation communities, excluding AGH and AHM, exhibited similarity in terms of means (group **a**); all communities, apart from AGH and AJK, recorded similar means (group **b**), whereas AGH, AHM, AHR, AQR and ASQ displayed commonality (Tukey group **c**).

Means of moisture by volume varied approximately 0.5-fold, where vegetation community AGH recorded 57.5 ± 2.8 to that of 78.1 ± 2.3 observed in AJK. The smallest moisture ranges/spreads were found in AQR (41.6-91.9, 50.3) and AJK (48.1-98.6, 50.5), with the largest range observed in AGH (5.5-91.3, 85.8). The lowest moisture recorded (5.5) was in AGH, while all communities recorded moisture values exceeding 90%, the highest was found in AJK (98.6).

Bulk density – 2 levels of difference: all communities, except for AJK and ARH, recorded similar means (Tukey group **a**), while all communities, except for AGH, displayed similarity (group **b**).

Variation in means for bulk density was less than two-fold, ranging from 0.36 ± 0.04 (ARH) to 0.61 ± 0.04 (AGH). The lightest soils were found in ARH (0.08) and AJK (0.09), with the heavier soils present in ASQ (1.56) and AJK (1.47). The smallest bulk density ranges/spreads were exhibited by communities ARH (0.08-1.28, 1.20) and AHR (0.12-1.33, 1.21), while the largest range was found in ASQ (0.14-1.56, 1.42).

LOI550 – 2 levels of difference: all vegetation communities, with the exclusion of AGH, AQR and ASH, shared commonality in terms of means (group **a**), and all communities, except for AHR, AJK and ARH, had similar means (Tukey group **b**).

LOI850 – 2 levels of difference: a reflection of LOI550, except that community ASH was included in group **a**.

LOI550 means differed approximately 0.5-fold between AQR (21.1 ± 3.5) and AHR (35.24 ± 3.39) and AJK (35.0 ± 3.3). The smallest range was recorded in community ASH (1.8-56.0, 54.2), the largest ranges observed in ARH (1.3-78.9, 77.6) followed by AGH (0.8-71.9, 71.1). Each vegetation community displayed low minimum LOI values ranging from 0.8 (AGH) to 3.1 (AHR), with maximum values ranging 48.6 (AQR) to 74.1 (AJK).

Peat composition – 2 levels of difference: all vegetation communities, to the exclusion of AGH, displayed similarity in terms of means (Tukey group **a**), while AGH, AJK and ARH had similar means (group **b**).

A three-fold variation in means was observed in peat composition between AGH (14.89 ± 3.26) and AQR (45.69 ± 8.53). However, all vegetation communities recorded minimum values of zero and maximum values of 87.5, thus all with a similar range/ spread (0.0-87.5, 87.5).

Sand composition – 0 levels of difference: all communities recorded similar means, there was no significant difference in this group between any members.

Reflecting peat composition, sand composition variation in means was found to be nearly three-fold between AHR (12.80 ± 4.40) and AQR (32.50 ± 8.64). All vegetation communities recorded minimum values of zero and maximum values of 87.5, thus all with the same range/spread (0.0-87.5, 87.5).

Loamy-soil composition – 3 levels of difference: AGH was the sole member of Tukey group **a;** all vegetation communities, except for AGH, AQR and ASQ, exhibited similar means (group **b**), whereas AHR, AQR, ASH and ASQ displayed commonality in terms of means (group **c**).

Difference in means for loam soil composition was seven-fold between AQR (6.94 ± 2.93) and AGH (48.30 ± 3.98). Each vegetation community recorded a minimum loamy-soil value of zero and all except for AQR (37.50), displayed a maximum value of 87.5.

Summary – vegetation community groups HSD

Three levels of difference are observed in five edaphic factors, bare ground, organic layer depth, EC, moisture by volume and loamy-soil composition. Five other factors, pH, bulk density, LOI550 and LOI850, and peat composition display two levels of difference, and the last, sand composition, has no levels of difference (as all vegetation groups had similar means). Applying a similar analysis of that used earlier (see Section 4.4.6, Regionalisation and edaphic factors review, page 4.96), vegetation communities score three in the greatest levels of difference, and 25 total levels of difference. This positions vegetation midrange to regionalisation types (Table 4.30) with IMCRA and IBRA still in leading positions in the table, with the two regionalisations being the best placed in relation to identifying coastal saltmarsh soil types.

Reviewing the vegetation group edaphic factor boxplots (Figures 4.95 to 4.105), it is clear that in many cases, though vegetation group medians are different, most interquartile ranges (the interpreted habitable zone of each vegetation group) overlap (e.g. organic layer depth, EC, moisture, LOI treatments). This suggests that most vegetation groups could survive and thrive in many areas. Thus, from the above it can be interpreted that vegetation communities are not a reflection of soil type.

4.5 Conclusions

As Tasmania has a characteristic array of coastal saltmarsh plants and a complex matrix of plant species associations which form diverse vegetation communities (see Chapter 3), it is difficult to compare results above with work elsewhere. No previous published studies have attempted to fit coastal saltmarsh soils (and their vegetation) to candidate regionalisations of natural areas. Rather than being community focused, most work has centred on individual plant species correlated to individual edaphic factors (this is addressed in Chapter 6 in this study).

An analysis of saltmarsh soil edaphic factors as stand-alone, result in the greatest levels of difference, suggesting that there is a significant difference between all soil factors and all soil types. It is highly likely that individual factors, such as EC and peat composition (and others, e.g. LOI treatments and pH) can be used to determine soil types.

Analysis of climate variables based on saltmarsh soil types produced a less clear-cut result, nonetheless two variables, temperature and rainfall, could be suitable attributes

to assist in broadly classifying soil type groups. However, this would be quite simplistic as only two classifications would be determined, wet + cold, and dry + warm. Other classifications could be identified from this (e.g. wet + warm), though, this would be an interpretation only.

As soil group indicators, no single plant species was found to be restricted to one soil type. Many species inhabit several soil type groups, for example, *J. kraussii, S. quinqueflora* and *S. radicans* occupied all eight soil type groups and are therefore deemed as common widespread species; *S. repens* is found in six groups; *T. arbuscula* found in five groups, while *A. stipoides* and *D. crassifolium* are found in three soil type groups. One group, soil type 6, has two indicator species, *T. arbuscula* and *S. repens*, however, once the three common species are included, this soil type loses its identifying uniqueness and makes selection of this soil type based on plants species much more difficult in the field.

Of the five regionalisation types considered (IBRA, IMCRA, BOM coastal districts, geographic and estuarine classes), IMCRA has been found to be the best regarding defining saltmarsh soil types by region. In terms of most significant differences (the ANOVA F value), IMCRA greatly surpasses its nearest rival, IBRA. In terms of levels of difference (Tukey HSD results), IMCRA again has the greatest levels of difference and the highest number of levels of difference, this time ahead of Geographic regionalisation.

It would have been expected that vegetation communities are a response to soil type. However, this is not necessarily so as most vegetation communities are found across all soil types, many in overlapping habitat envelopes. This then suggests that soil type is a response to plant species association(s), where, either individual plants species, or a combination of plant species, even when species randomly enter a vegetation community, can modify soil conditions to improve continued existence of those species either individually or combined as a community.

The conclusion is that most saltmarsh soil types are not confined to regions (although it has been identified that IMCRA regionalisation is a possible candidate for classifying soil types), nor are vegetation communities confined to individual soil types. The results clearly demonstrate that in many cases soil type does not identify with individual

vegetation communities, rather that communities appear to be highly adaptable to various soil types and conditions. Vegetation communities do not necessarily modify soil conditions to suit themselves, as the range within individual edaphic factors is too large.

Further research

Obviously, there are unanswered questions to this study as no clear and unambiguous result has been obtained. There are some steps that can be taken to further clarify the relationships between soil type and regionalisation and vegetation communities. These include:

- Identification of the tidal amplitude and inundation period for individual plots;
- Determination of saltmarsh age;
- Appreciation of position in the landscape;
- Sediment source (terrestrial or marine);
- Determination of geological and hinterland influences; and
- Elevation above mean tide height of individual plots.

Or, maybe there is no unequivocal answer; this is nature at its best and no further clarity is needed!

Finally, the study aims have been largely realised. A classification of plots based on edaphic factors has been prepared, and individual soil type groups analysed for differences between groups. Climate variables have been aligned to soil groups, and these too have been analysed for difference between soil types. An extensive analysis of soil types and their relationship to various regionalisations was carried out and tested for differences. Plant species indicators were determined for each soil type, and previously determined vegetation communities were aligned to individual edaphic factors and again tested for differences between communities.

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4.8 Appendices

4A.1 Edaphic factor grouping dendrogram

4A.2 Soil type groups edaphic factors boxplot values

4A.3 Vegetation groups edaphic factors boxplot values

4A.1 Edaphic factor grouping – dendrogram

Figure 4A.1: Dendrogram of all plots based on edaphic factors and generated from Flexible β clustering using Bray-Curtis dissimilarity measure. The dendrogram has been "cut" to eight soil types at a level of 4.0.
Note: this figure is provided to demonstrate the grouping attained from clustering.

4A.2 Soil type groups – edaphic factor boxplot values

Table 4A.2: Minimum, 1st, 2nd and 3rd quartile, and maximum values by soil type group by each edaphic factor. The areas shaded light green are the edaphic factor ranges (inter-quartile range) in which each soil type is found and is an indication of "ecological/best fit" for that community within that individual edaphic factor. Order of edaphic factors are by boxplots presented above.

Edaphic factor	Soil type group >	1	2	3	4	5	6	7	8
Bare ground (%)	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1st quartile	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00
	Median	3.00	0.00	3.00	15.00	15.00	3.00	15.00	3.00
	3rd quartile	15.00	3.00	15.00	37.50	15.00	15.00	37.50	15.00
	Maximum	37.50	3.00	37.50	87.50	37.50	37.50	62.50	37.50
O layer depth (cm)	Minimum	2.00	9.00	2.00	0.00	4.00	5.00	2.00	10.00
	1st quartile	9.50	19.00	7.50	1.00	10.00	13.50	8.00	15.00
	Median	10.50	28.00	13.00	3.00	12.00	23.00	10.00	28.50
	3rd quartile	15.00	34.00	22.50	4.00	15.00	33.00	15.00	34.50
	Maximum	20.00	42.00	37.00	8.00	20.00	45.00	21.00	40.00
pH	Minimum	4.36	4.91	4.51	6.02	4.92	4.90	5.85	4.81
	1st quartile	5.42	5.47	5.99	7.10	5.84	5.73	6.52	5.50
	Median	6.18	5.85	6.56	7.65	6.20	6.00	6.74	5.74
	3rd quartile	7.30	6.10	7.27	7.99	6.52	6.34	7.10	6.18
	Maximum	8.36	6.69	8.05	8.17	7.33	7.16	7.90	6.89
EC (dS/m)	Minimum	0.80	20.22	1.89	0.40	0.48	2.20	2.01	2.48
	1st quartile	2.95	32.63	9.30	1.95	4.43	20.51	8.40	13.71
	Median	4.35	41.60	15.24	2.93	7.25	27.90	11.47	24.17
	3rd quartile	6.05	53.13	21.31	4.72	12.82	36.64	15.68	31.86
	Maximum	10.43	65.90	32.11	7.56	23.32	56.03	24.29	49.43
Moisture by volume (%)	Minimum	11.34	65.41	40.31	5.54	51.55	54.71	46.94	58.18
	1st quartile	24.29	76.15	57.24	30.23	60.42	73.53	61.17	73.41
	Median	33.61	84.20	74.15	39.33	64.79	82.12	68.06	77.59
	3rd quartile	47.43	87.45	79.66	49.12	73.27	87.03	72.41	84.11
	Maximum	58.32	98.50	94.68	62.69	83.89	98.60	89.25	94.60
Bulk density (g/cm^3)	Minimum	0.26	0.11	0.26	0.75	0.25	0.08	0.29	0.09
	1st quartile	0.66	0.15	0.35	1.08	0.38	0.19	0.55	0.14
	Median	0.79	0.17	0.44	1.22	0.55	0.24	0.66	0.17
	3rd quartile	0.99	0.19	0.56	1.39	0.62	0.31	0.86	0.20
	Maximum	1.43	0.23	0.84	1.56	0.97	0.46	1.15	0.26
LOI550 (%)	Minimum	2.89	25.69	5.76	0.81	1.44	5.59	3.12	24.59
	1st quartile	6.29	40.35	16.18	1.36	15.91	25.59	5.80	41.45
	Median	9.36	46.15	20.49	2.36	18.80	34.01	8.40	51.50
	3rd quartile	13.69	52.01	26.76	3.46	28.00	42.52	16.16	60.32
	Maximum	23.65	66.27	37.15	5.56	42.95	64.07	31.16	78.85

Edaphic factor	Soil type group >	1	2	3	4	5	6	7	8
LOI850 (%)	Minimum	3.01	38.00	7.11	1.17	1.78	7.55	3.77	28.20
	1st quartile	6.92	47.66	19.12	2.95	17.61	30.23	6.96	44.96
	Median	11.58	51.90	25.42	4.58	20.55	38.92	10.43	54.49
	3rd quartile	15.94	57.57	30.36	5.67	29.60	46.77	17.54	63.55
	Maximum	26.97	69.59	42.68	7.71	44.20	70.15	32.28	80.65
Peat (%)	Minimum	0.00	87.50	0.00	0.00	0.00	37.50	0.00	0.00
	1st quartile	0.00	87.50	0.00	0.00	0.00	62.50	0.00	5.00
	Median	0.00	87.50	17.50	0.00	0.00	62.50	0.00	27.50
	3rd quartile	0.00	87.50	17.50	0.00	0.00	87.50	17.50	37.50
	Maximum	0.00	87.50	37.50	0.00	0.00	87.50	37.50	62.50
Sand (%)	Minimum	0.00	0.00	0.00	87.50	0.00	0.00	17.50	0.00
	1st quartile	2.50	0.00	0.00	87.50	0.00	0.00	37.50	0.00
	Median	17.50	0.00	0.00	87.50	5.00	0.00	62.50	0.00
	3rd quartile	37.50	0.00	5.00	87.50	17.50	2.50	62.50	0.00
	Maximum	62.50	0.00	5.00	87.50	37.50	5.00	87.50	0.00
Loamy-soil (%)	Minimum	0.00	0.00	0.00	0.00	37.50	0.00	0.00	17.50
	1st quartile	37.50	0.00	5.00	0.00	62.50	0.00	0.00	37.50
	Median	62.50	0.00	17.50	5.00	62.50	0.00	17.50	62.50
	3rd quartile	87.50	0.00	37.50	5.00	87.50	17.50	37.50	62.50
	Maximum	87.50	0.00	37.50	5.00	87.50	37.50	62.50	87.50

4A.3 Vegetation groups – edaphic factors boxplot values

Table 4A.3: Minimum, 1st, 2nd and 3rd quartile, and maximum values by vegetation community (see Chapter 3) by each edaphic factor. The areas shaded light green are the edaphic factor ranges (inter-quartile range) in which each community is found and is an indication of "ecological/best fit" for that community within that individual edaphic factor. Order of edaphic factors are by boxplots presented above.

Edaphic factor	Vegetation com. >	AGH	AHM	AHR	AJK	AQR	ARH	ASH	ASQ
Bare ground (%)	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1st quartile	0.00	0.00	0.00	3.00	3.00	0.00	15.00	0.00
	Median	3.00	3.00	0.00	15.00	3.00	3.00	15.00	3.00
	3rd quartile	15.00	15.00	15.00	37.50	15.00	15.00	37.50	15.00
	Maximum	37.50	37.50	15.00	87.50	15.00	37.50	62.50	37.50
O layer depth (cm)	Minimum	0.00	1.00	3.00	0.00	2.00	2.00	0.00	1.00
	1st quartile	10.00	10.00	15.00	12.00	7.00	10.00	10.00	9.00
	Median	12.00	15.00	20.00	27.00	12.00	16.00	13.00	15.00
	3rd quartile	20.00	23.00	35.00	37.00	15.00	33.00	21.00	25.00
	Maximum	35.00	37.00	45.00	45.00	22.00	43.00	36.00	37.00
pH	Minimum	4.66	3.86	4.36	4.20	5.13	4.81	5.10	4.45
	1st quartile	5.84	5.25	5.58	5.39	5.97	5.67	6.23	5.71
	Median	6.36	5.95	6.11	5.80	6.57	5.96	6.62	6.10
	3rd quartile	7.26	6.48	6.60	6.39	6.90	6.25	7.11	6.74
	Maximum	8.17	8.00	7.90	7.22	8.13	6.97	8.15	8.14
EC (dS/m)	Minimum	0.54	0.99	1.95	1.58	0.79	0.40	4.11	1.89
	1st quartile	3.11	5.57	9.58	8.70	12.27	5.25	11.90	10.06
	Median	6.08	20.00	20.65	15.90	20.67	11.91	21.13	23.43
	3rd quartile	16.87	32.22	26.13	26.06	37.05	23.49	32.63	40.17
	Maximum	32.34	64.63	46.37	41.05	43.65	45.85	60.70	65.90
Moisture by volume (%)	Minimum	5.54	18.72	31.60	48.07	41.55	30.00	34.94	24.20
	1st quartile	43.82	56.62	59.85	69.83	65.27	61.99	61.41	57.29
	Median	63.07	68.47	75.90	80.31	74.06	77.30	73.95	71.60
	3rd quartile	74.97	82.02	82.59	86.72	83.90	83.40	81.23	84.20
	Maximum	91.26	94.71	92.35	98.60	91.89	98.50	91.71	92.88
Bulk density (g/cm^3)	Minimum	0.12	0.12	0.12	0.09	0.17	0.08	0.13	0.14
	1st quartile	0.25	0.20	0.16	0.17	0.22	0.15	0.24	0.21
	Median	0.61	0.29	0.23	0.26	0.38	0.23	0.46	0.34
	3rd quartile	0.88	0.61	0.49	0.54	0.86	0.39	0.66	0.61
	Maximum	1.39	1.13	0.90	1.08	1.43	0.65	1.02	1.13
LOI550 (%)	Minimum	0.81	1.19	3.06	1.84	1.35	1.26	1.77	1.15
	1st quartile	8.90	16.29	23.28	23.37	7.39	15.44	12.33	11.73
	Median	18.36	26.79	35.10	33.44	19.21	35.43	20.63	26.49
	3rd quartile	33.55	42.43	50.92	50.83	30.29	49.26	32.20	41.86
	Maximum	70.28	67.45	68.77	74.09	48.64	78.85	55.98	60.08

Edaphic factor	Vegetation com. >	AGH	AHM	AHR	AJK	AQR	ARH	ASH	ASQ
LOI850 (%)	Minimum	1.17	2.69	4.95	4.46	2.95	1.56	2.76	2.08
	1st quartile	10.55	17.93	25.42	27.80	9.26	17.26	15.36	12.99
	Median	20.73	30.03	37.45	38.60	23.09	39.93	27.02	31.83
	3rd quartile	36.12	46.64	54.33	54.68	33.25	53.03	37.72	46.70
	Maximum	73.14	69.72	72.79	77.21	54.37	80.65	62.47	67.33
Peat (%)	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1st quartile	0.00	0.00	17.50	0.00	0.00	0.00	0.00	0.00
	Median	0.00	37.50	37.50	17.50	62.50	17.50	17.50	62.50
	3rd quartile	17.50	62.50	62.50	37.50	87.50	62.50	87.50	87.50
	Maximum	37.50	87.50	87.50	87.50	87.50	87.50	87.50	87.50
Sand (%)	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1st quartile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Median	0.00	0.00	0.00	0.00	17.50	0.00	5.00	0.00
	3rd quartile	17.50	17.50	17.50	17.50	62.50	37.50	37.50	37.50
	Maximum	37.50	37.50	37.50	37.50	87.50	87.50	87.50	87.50
Loamy-soil (%)	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1st quartile	17.50	0.00	5.00	0.00	0.00	5.00	0.00	0.00
	Median	62.50	17.50	17.50	17.50	0.00	37.50	5.00	5.00
	3rd quartile	87.50	50.00	37.50	62.50	5.00	37.50	37.50	17.50
	Maximum	87.50	87.50	62.50	87.50	5.00	62.50	87.50	37.50

Chapter 5

Carbon stock of Tasmanian coastal saltmarshes

Chapter 5 – Table of contents

Chapter 5: Carbon stock of Tasmanian coastal saltmarshes

5.1 Introduction

Wetlands are now understood to represent the greatest portion of the terrestrial carbon pool (Dixon & Krankina 1995) and play a vital role in global carbon cycles (Sahagian & Melack 1997). Saltmarshes, a significant component of wetlands, contribute to carbon sequestration and storage (Macreadie *et al.* 2017), functions now becoming widely recognised (Chmura *et al.* 2003; Lewis *et al.* 2018). It has been estimated that globally saltmarshes account for the highest carbon accumulation rate amongst all ecosystems, signifying the considerable importance of this ecosystem (Ouyang & Lee 2014). The most dominant source of this carbon is in-situ storage with saltmarsh carbon stock greatest in temperate regions (Saintilan *et al.* 2013).

Until recently, vegetated coastal ecosystems (e.g. mangroves, tidal saline wetlands), were not explicitly part of estimates of stored carbon (Mcleod *et al.* 2011), thus, a serious gap existed in quantifying global carbon stocks. This changed when recent studies highlighted the capacity of carbon stocks within coastal ecosystems (Chmura *et al.* 2003; Duarte *et al.* 2004) and stressed the importance of this environment in sequestrating carbon (Laffoley & Grimsditch 2009; Nellemann & Corcoran 2009).

Unfortunately, the global size and carbon stock of coastal saltmarshes have an extensive range, creating difficulties in determining a comprehensive value of saltmarsh carbon sequestration and storage. This limits the full appreciation of the significance of coastal ecosystems in general, let alone saltmarshes. Estimates by Chmura *et al.* (2003) and Duarte *et al.* (2004) suggest the global expanse of coastal saltmarshes range from 22,000 to 400,000 square kilometres, and a carbon sequestration of between (mean, standard error) 4.8 ± 0.5 and 87.2 ± 9.6 tetragrams (Tg) per year. Not only are these figures substantial, the range of the attributes is large (nearly 20-fold). Chmura *et al.* (2003) estimates that the carbon store of saltmarshes to be 430 ± 30 Tg, this with a caveat that the estimation is based on soil depth of 0.5m. However, saltmarsh soil depths are highly variable and can average 1 metre; therefore, global carbon stocks sequestered in saltmarshes can exceed 10,000 Tg (Chmura *et al.* 2003). From the literature, estimations appear to be the norm, thus limiting, and often misrepresenting, the true value, whether it be economical or by ecosystem services. Reliable data for coastal tidal marshes is

available from the Mediterranean region, North America and the Indian Ocean (Lewis *et al.* 2018), with several authors calling for studies of carbon stocks to focus on under-represented areas (Mcleod *et al.* 2011; Lavery *et al.* 2013; Macreadie *et al.* 2014) and the application of greater sampling frequency in individual regions (Lewis *et al.* 2018).

Carbon accounting must include coastal tidal wetlands as current research points to high sequestered stocks, however inclusion in carbon trading, incentive schemes and carbon offsets are contingent on better data (Saintilan *et al.* 2013) and a fairer and more diverse representation by study sites.

5.1.1 Australian studies

Australian coastal saltmarshes are vast with an estimated area of 1.4 million hectares (Macreadie *et al.* 2017). They are generally considered to be poorly understood and neglected (Fairweather 1990; Saintilan & Adam 2009; Boon 2011). However, recent studies, for example Macreadie *et al.* (2013), Saintilan *et al.* (2013), Lovelock *et al.* (2014), Kelleway *et al.* (2016a), Owers *et al.* (2016), Kelleway *et al.* (2017), Macreadie *et al.* (2017), Lewis *et al.* (2018), have made significant inroads into the understanding of carbon sequestration rates and sequestered stocks either on a localised, state-wide or nationwide basis. This has certainly informed debate to the value, both in monetary and ecosystem services terms, of these once maligned ecosystems and has fostered a cohort of national organisations (e.g. Cradle Coast NRM, NRM South) and local individual groups (e.g. Marion Bay Coastcare, Circular Head Landcare) interested in preserving and protecting coastal saltmarshes.

As Australia now includes "blue" carbon (carbon stored in coastal and marine ecosystems) in the National Greenhouse Gas Inventory (Department of the Environment and Energy 2017), there is a need to accurately determine current carbon stock values along and around the Australian coastline, (Macreadie *et al.* 2017). As more information comes to hand, improvements can be made to current estimates, a more comprehensive value applied and most importantly, shortfalls and gaps in knowledge can be addressed. Of all seven coastal States and Territory, just two, NSW and Victoria, have been somewhat adequately assessed (25 and 45 sites respectively) for carbon sequestration rates and total carbon stocks (Saintilan *et al.* 2013; Lewis *et al.* 2018). On the other hand, Queensland, South Australia and Western Australia have had 6, 3 and 4

(respectively) sites assessed, while none have been assessed in the Northern Territory and Tasmania (Macreadie *et al.* 2017), other than some non-native plant species sites in Tasmania's northwest. Carbon stocks have been calculated for the under- and non-representative States (and Territory), either based on limited study sites or means from other states combined, this impacting on the robustness and veracity of the final results of carbon stocks and sequestration rates. Furthermore, although Australian carbon sequestration rates and stock values are analogous to those globally (Livesley & Andrusiak 2012; Lovelock *et al.* 2014; Ouyang & Lee 2014), consideration should be given to the geographical position and geomorphological settings of study sites and encompass various vegetation communities (Saintilan *et al.* 2013; Lovelock *et al.* 2014).

5.1.2 Assessment of carbon store

For many years the measurement of stored carbon has been made either by use of the of loss on ignition (LOI) process and converting the organic matter component following LOI to a carbon value, or by the wet oxidation method, for example Walkley-Black and various modifications, such as Tinsley (Chatterjee *et al.* 2009). The use of a conversion of LOI to carbon, especially that derived from a specific study site and applied to another site that has no resemblance to the original site, is troublesome as results are not authenticated and subsequent estimates of carbon stocks could range from being wildly inaccurate to totally invalid. Additionally, vegetation patterns display varying levels of stored carbon as shown by studies in SE Australia, principally New South Wales (Saintilan *et al.* 2013) and Queensland (Lovelock *et al.* 2014).

In recent time, improved carbon analysis has been made by dry combustion methods where no conversions are required, although this method determines total carbon, rather than organic carbon. This can be overcome with appropriate treatment of soil samples by acidification to remove inorganic carbon, however, the dry combustion method, though touted as being highly accurate, is very costly and conducted in specialised laboratories. Therefore, there is still a place and a need for estimating carbon values from LOI determinations (at a far lower cost than that by dry combustion) and application of a locally derived and tested conversion or conversions. This will provide greater credence to carbon values in coastal tidal marshes, and importantly provide a basis of carbon stock than can be remeasured in the future to determine losses and gains over time.

5.1.3 Questions and study aims

This study focuses on native coastal saltmarshes, those vegetated by native plant species, rather than non-native saltmarshes vegetated by the noxious plant *Spartina anglica* (commonly known in Tasmania as rice grass). No sites assessed in this study exhibited *S. anglica*.

The chapter aims to provide a credible and robust assessment of carbon stock for Tasmanian coastal saltmarshes. Initially, this requires the development of a suitable conversion of LOI values to total carbon, then applying this conversion to determined LOI values for all plots. The resulting carbon store value will update the overall estimation of Australian tidal marshes carbon stocks. Furthermore, carbon stock differences between individual vegetation communities can be calculated, and finally, determine whether identical vegetation communities have similar carbon values in differing IMCRA regions

Questions

1. Is there a relationship between LOI at 550^{o}C (LOI550), LOI at 850^{o}C (LOI850) and organic carbon for Tasmanian coastal saltmarsh soils? If so, is the relationship robust enough to develop a suitable conversion from LOI550/LOI850 to organic carbon, thus avoiding the high cost of determining carbon by dry combustion methods?
2. What is the current organic carbon stock of Tasmania's coastal saltmarshes?
3. Are there differences in organic carbon stock values between vegetation community groups in Tasmanian coastal saltmarshes?
4. Do similar vegetation community groups in different IMCRA3.3 bioregions (see Chapter 1: Introduction: regionalisation of Tasmania's natural areas, and Chapter 3: Classification of coastal saltmarsh vegetation of Tasmania) display similar soil carbon density values?

Study aims

A frustration in making progress in carbon stock evaluations is the uncertainty in the precision of published estimates; many studies use generic conversions, which, although they have their place, are not precise enough. In an attempt to properly and precisely estimate Tasmanian saltmarsh carbon stores, the study aims include:

- Test the validity of widely used methods in determining loss on ignition values and formulating conversions to carbon;
- Establish robust conversion formula/formulae for organic carbon that can be applied to LOI results from Tasmanian coastal saltmarshes as:
- A generic conversion (can be applied to all Tasmanian sites irrespective of geographical and or geomorphological position), and
- Specific conversion/conversions based on individual vegetation communities (those determined in Chapter 3);
- Provide a robust and reliable estimate of stored organic carbon in Tasmanian coastal saltmarshes that would update existing Australian estimates and accurately reflect Tasmania's contribution to the sequestered carbon store;
- Establish whether individual vegetation communities have similar carbon stores; and
- Determine if IMCRA3.3 regionalisation highlights differences in carbon stock values, particularly within and between individual vegetation communities.

We now have access to a large dataset of field observations (vegetation – Chapter 3) and laboratory measurements (soil – Chapter 4: Soils of Tasmanian coastal saltmarshes) from 91 sites/407 plots plus supplementary data from a previous study (Aalders 2014) and ancillary data from this study. Furthermore, previous analyses in both Chapters 3 and 4 have identified that saltmarsh regionality based on IMCRA3.3 (hereafter IMCRA) best describes saltmarsh geographical position in the landscape. This chapter uses the eight vegetation groups previously determined with associated IMCRA regions, and edaphic factors of organic layer depth, soil bulk density, LOI550 and LOI850 for each individual plot. Statistical analysis of the dataset examines correlations between factors and investigates patterns between various ranges of LOI550/LOI850 and total carbon and individual vegetation groups. From this we can:

- Determine correlations between both LOI550 and LOI850 and total carbon;
- Formulate a conversion factor from LOI550 to organic carbon suitable for overall use on Tasmanian coastal saltmarsh soils;

- Formulate conversion factors from LOI550 to organic carbon for individual vegetation community groups previously determined (see Chapter 3);
- Determine organic carbon stock values by individual Tasmanian coastal saltmarsh vegetation communities;
- Provide an estimation of organic carbon stock in Tasmania's coastal saltmarshes and its current monetary value; and
- Determine whether identical vegetation groups from differing IMCRA bioregions have similar organic carbon stock values (per hectare).

5.2 Methods

The use of, for example, LOI at 375, implies LOI at 375°C. Therefore, all LOI treatment values below refer to degrees centigrade. Preliminary sites *(n* = 21) are those assessed for suitability as Training sites (positioned state-wide) for this study. Soil samples were collected from plots *(n* = 110) at these sites to test sampling and laboratory processes (e.g. SBD, pH, LOI550 and 850, total carbon analysis). Rather than squander those results they were incorporated into this segment of the study.

5.2.1 Loss on ignition

LOI has been used for many years by soil scientists, geographers and geologists as a reliable technique in the measurement of carbon (Konen *et al.* 2002). It is a safe, quick and relatively cheap process (Craft *et al.* 1991; Navarro *et al.* 1993; Pribyl 2010) and requires simple laboratory equipment (Rayment & Lyons 2011). This method has been described as one of the more accurate methods of assessing OC in soils (Navarro *et al.* 1993). Yet, it does have some limitations with the accuracy of the result being dependent on a number of factors such as size of sample and position in furnace (Heiri *et al.* 2001), the dryness of the sample (Pribyl 2010), temperature of the furnace and heating times (Ball 1964; Matthiessen *et al.* 2005), the sample's composition (Pribyl 2010), the loss of structural water from carbonaceous materials (clays) and CO_2 from soil carbonates (Ball 1964; Navarro *et al.* 1993) and an appreciation of the sample's thermal properties (Boyle 2004).

A study by Heiri *et al.* (2001) considered whether the position within the furnace and the size of the sample affected LOI results. Their study found that smaller samples lost

weight faster than larger ones, and that samples placed in the centre of the oven lost greater weight than those on the margins. Heiri *et al.* (2001) concluded that time in the furnace, sample size and position in the oven were major factors impacting LOI results, and that laboratory weighing of samples should be undertaken with care.

Sample dryness is critical when accuracy is necessitated. Adequately drying a sample at low temperature before LOI treatment will ensure that weight loss of hydrated water is not a consideration when calculating loss of organic matter. A moist/wet sample will inflate the LOI value as the moisture weight loss of the sample during ashing will be assumed to be part of the organic matter loss (Pribyl 2010). Drying the sample at 105^{o}C prior to treatment for 24 hours will ensure hydrated water removal without affecting soil characterisation (Rayment & Lyons 2011).

Several authors, including Ball (1964), Boyle (2004) and Matthiessen *et al.* (2005) reviewed furnace temperatures and heating periods during LOI treatments. Treatments of non-calcareous soils (little or no carbonates present) by LOI at 375 and 850 showed good correlations against organic carbon, although ashing times were different (ranging from one to 16 hours). Ball (1964) proposed two equations (for conversion of LOI treatment to organic carbon), one based on LOI at 375, the other on LOI at 850, although claimed accuracy of LOI at 375 was greater, thus recommended for use. Using samples derived from compost and manure, Matthiessen *et al.* (2005) tested forty-two temperature-heating/length-of-time combinations ranging from LOI at 400 to LOI at 650 by one to 24 hours. The authors found that as ashing time increased, the difference of ash content from the lowest temperature to the highest temperature decreased. Likewise, as the temperature increased, the difference in ash content decreased from the shortest time to the longest ashing time. Boyle (2004) however, reports that low temperature ignition, especially under 550^{o}C, results in an underestimation of total SOM as the more humified component of organic matter is not consumed during ignition. This is an important aspect when ashing soils containing high levels of organic matter (or conversely, soils that contain a low level of mineral matter). Ball (1964) and Matthiessen *et al.* (2005) concluded that LOI550 is preferable, and both state that ashing for 2 hours produced satisfactory results. At this temperature and time, costs were also reduced due to energy and time savings.

The calcareous (carbonate) component of the soil sample is also considered an important aspect that must be addressed. Substantial errors in the estimation of organic carbon can be due to high levels of carbonate material (e.g. shell) and ashing at a temperature that is high enough to oxidise carbonates (Pribyl 2010). This will decrease the residual sample weight (following LOI), increase the value of loss on ignition, resulting in a "false" value of organic carbon. Therefore, time and temperature are critical factors when it comes to reducing the loss of CO_2 and the influence of carbonates during the LOI treatment (Chatterjee *et al.* 2009). There is little consensus in the published literature on time and temperature that in one instance is long enough (time) and high enough (temperature) to ash all organic matter, yet, is short enough (time) and low enough (temperature) to avoid calcination and loss of clay structural water. There are recommendations of ashing at 430^{o}C for 24 hours, 400^{o}C for 8 hours, while others propose higher temperatures of 600^{o}C and 1025^{o}C (Navarro *et al.* 1993). Ball (1964) argues that as losses of CO_2 from carbonates occur at high temperatures (it is assumed that he refers to greater than 850^{o}C, as this temperature was used in his study for testing organic carbon), reduction of any error due to the presence of carbonates can be either eliminated or decreased by maintaining lower operating temperatures during LOI. In conclusion, Rayment and Lyons (2011) recommend ashing at 550^{o}C for two hours to determine organic matter content, and further ashing at 950^{o}C for a further two hours if an estimate of soil carbonate content is required.

Laboratory analysis

Preparation of standards and validation of furnace

Considering the discussion above (particularly size of the sample, position in the furnace and ashing time), preparatory steps were undertaken to validate the precision of the furnace used for all LOI treatments.

- Four standards were prepared from samples collected during an earlier study (Aalders 2014). Material from each standard was sieved on a 2mm screen, obvious plant material removed prior to sieving. All <2mm material was retained for analysis. The LOI values of the standards ranged from 10 to 50% (an estimated range of LOI values of Tasmanian coastal saltmarsh soils). The LOI550 values for each standard are the means obtained from 12 separate runs in two different laboratories at the University of Tasmania, Sandy Bay campus.

Subsequently, each standard was analysed for total carbon, each seven times to obtain a mean of TC;

- All material was placed in a drying cabinet set at 105°C overnight prior to the first run and left in the cabinet for the duration of all LOI tests of the furnace. All crucibles were oven dried at similar temperature and maintained in dry state until LOI of standards completed. The furnace (Woodrow Kiln, model: Hobby Fire Mini, maximum settable temperature: 1280°C) held 48 samples. Sample weights prior to LOI treatment were random, all weighing carried out on the same set of scales, each weight recorded to 3 decimal places. Each standard was run once in the furnace (n = 48) and results tabulated to a spreadsheet and mean, median, standard deviation, standard error, CV (coefficient of variation), and range calculated for each run of 48 samples. Next, sample weights to 0.5 grams brackets were segregated (e.g. 1.0 to 1.5g, 1.51 to 2.0g, and so on) and LOI values for each weight bracket were calculated for mean, median, standard deviation, standard error, CV, and range, this to determine the impact, if any, of sample size. Subsequently, LOI values of each row and column of sample placement in the oven was calculated for mean, median, standard deviation, and CV and then cross checked by row/column, this to determine the impact of position in the oven; and
- One standard was run four times at 2, 3, 4 and 5-hour intervals to check on differences in results.

LOI method applied

The following steps were applied to determine soil organic matter values of all samples from preliminary sites plots *(n* = 110) and study sites plots *(n* = 407):

- All material was sieved to <2mm, with all obvious plant matter removed prior to sieving;
- Each sample was oven dried at 105°C overnight and retained in oven until ashing of each sample had been completed in triplicate (minimum requirement);
- Prior to first ashing run, all crucibles were oven dried at 105°C overnight, any crucibles not used during any run was returned to the oven to maintain its dry state;

- Pre-ashing:
    - Each crucible was weighed empty to three decimal points, weight recorded;
    - Portion of each sample added to individual crucibles and weighed including crucible, weight recorded.
- Samples placed in oven, ramp rate set at 200^{o}C per hour, ashing temperature set at 550^{o}C, ashing time set for 3 hours, cooling ramp rate set at "nil" (oven allowed to cool at own rate), sample removed from oven when oven temperature below 200^{o}C;
- Each ashing run included at least one standard (see above), this to maintain a validation of process;
- Post-ashing:
    - Each crucible was weighed with remaining residue to three decimal points, weight recorded;
    - Crucible emptied, all residue removed, crucible weighed, weight recorded.
- LOI550 calculation:

$$\%LOI = [((W_{105} - Crucible_{pre}) - (W_{550} - Crucible_{post})) \times 100]/W_{105} \quad (5a)$$

Where:

W_{105} = weight of crucible and oven dried (to 105^{o}C) sample, pre-ashing,

$Crucible_{pre}$ = weight of the crucible pre-combustion at 550^{o}C,

W_{550} = weight of crucible and sample post ashing,

$Crucible_{post}$ = weight of the crucible post combustion at 550^{o}C.

The result reported as LOI at 550 (%) on an oven dry basis.

- The procedure was repeated (following LOI550 above) with ashing at 850^{o}C (to ash carbonates (inorganics) as well as organic matter) for 3 hours, followed by cooling in the furnace for approximately 6-8 hours to 200-220^{o}C prior to removing from furnace and reweighing. The organic and inorganic matter component of the soil was calculated as per LOI550 calculation above (replacing 550 with 850), the result reported as LOI at 850 (%) on an oven dry basis.

- All determinations for both LOI treatments (550 and 850) were run in triplicate: preliminary sites *(n* = 330 x 2), study sites *(n* = 1,221 x 2);
- All data entered to spreadsheet, mean, median and coefficient (CV) of each sample for each treatment calculated; if CV >10%, ashing of sample repeated until CV <10% (wherever possible); and
- The inorganic component of each sample was calculated by subtracting the LOI550 value from the LOI850 value.

To reduce the CV to below 10%, several samples *(n* = 35) were repeated for LOI550. In six cases (1.5%), this could not be achieved even although several samples were ashed 15 times. This is perhaps due to the very low SOM content of some samples, they being principally composed of sand. The mean of the final CV for all samples was 2.77% an indication of the high precision in the results.

Regarding LOI850 for study sites, few samples *(n* = 37) were repeated to reduce the CV to below 10%. In just three cases (0.75%), this could not be achieved, perhaps due to the very low SOM content of these samples, being principally composed of sand. The mean of the final CV for all samples was 2.99%, again, an indication of the high precision in the results.

It was expected (and subsequently found) that Tasmanian coastal saltmarsh soils were very low in inorganic matter (e.g. failed the "fizz" test, minor difference between LOI850 and LOI550), therefore they have been classed as non-calcareous soils.

5.2.2 Dry combustion

The development of carbon (in combination with other elements for example, sulphur and nitrogen) analysers that operate on dry combustion (DC) of the soil sample has become the standard (Craft *et al.* 1991; Konen *et al.* 2002; Chatterjee *et al.* 2009; Pribyl 2010). Reports from 14 separate studies have shown that there is a correlation of greater than 90% between this method and LOI (Pribyl 2010). Work by Konen *et al.* (2002) on 254 samples from five different study sites in north central USA, reported a relationship between LOI at 360°C (for two hours) and dry combustion of r^2 ranging from 0.94 to 0.98, with a mean of 0.97. A study by Craft *et al.* (1991) on 250 samples of estuarine marsh soils from North Carolina, showed a relationship between

organic carbon and LOI at 480°C (for eight hours) of $r^2 = 0.990$. Although DC has a greater precision then LOI (Konen *et al.* 2002; Chatterjee *et al.* 2009), the unit cost of this method is not cheap (Konen *et al.* 2002) – greater than $17 per sample following preparation (Chatterjee *et al.* 2009). In dry combustion, the soil sample, generally ground to less than 63µm and weighing approximately 100mg, is mixed with a catalyst, heated to approximately 1,000°C in a stream of pure oxygen allowing all carbon to be oxidised to CO_2. The CO_2 released is measured by solid state infrared absorption and converted to total carbon (TC) (Pribyl 2010). TC though, includes organic and inorganic carbon, therefore any carbonates in the soil are included in the TC value, whereas, LOI550 does not include carbonates as the LOI temperature needs to be over 800°C to incinerate carbonates (Rayment & Lyons 2011). Like that of carbon, other elements, such as sulphur and nitrogen, are released during the dry combustion, oxidised to SO_2/NO_2 and measured by the same method as that of carbon to provide total sulphur (TS)/total nitrogen (TN) content of the sample.

Fortuitously, an opportunity arose that gave access to a carbon analyser at the Geochemical Laboratory, School of Earth Sciences (University of Tasmania, Sandy Bay). The analyser, an ELTRA CS 2000, was fitted with a resistance furnace making it excellent for testing organic soils (Figure 5.1).

Figure 5.1 ELTRA CS 2000 analyser.

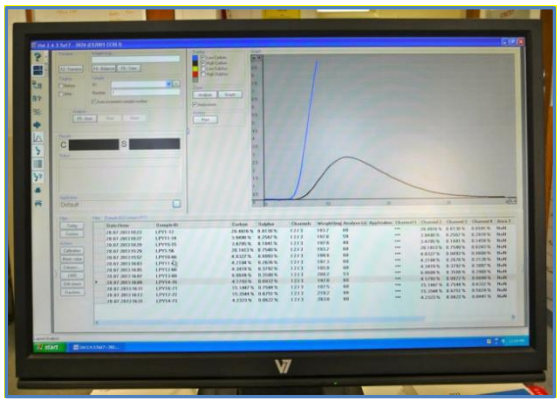

Figure 5.2: Screen-shot of a processed soli sample.

The standard procedure for carbon analysis in the ELTRA, outlined in the operating manual, was followed. A ground sub-sample (to less than 500µm in size) of approximately 0.2g of each of soil sample was weighed to three decimal places and added to the ELTRA along with accelerants (pure iron and pure tungsten) and a TC value were obtained within 60 seconds (Figure 5.2). The result was expressed as a

percentage of TC by weight of the sample. Although there was a high per unit cost factor of this process (currently >$20 per sample!), carbon analyses of all samples were repeated another six times (all replicates were within 10% of the initial result). The ELTRA was calibrated prior to each run (n = 5). Two carbon reference samples (ALPHA 4015 – carbon content 1.17%, and ALPHA 4007 – carbon content 7.27%) were analysed every 10 samples throughout all dry combustion analyses. Only samples from preliminary sites were analysed using the ELTRA.

5.2.3 Conversion of LOI to carbon

Historically, the estimate of OC has assumed that the OC to SOM conversion factor is 1.724 (SOM to OC of 58%), this conversion called the "van Bemmelen factor" or "Bemmelen factor". Yet, van Bemmelen was not the originator of this conversion; in 1890, he himself credited the conversion (of 1.724) to Wolff (1864) as did Detmer in 1871 (Pribyl 2010). The earliest assumption of 58% carbon in organic matter appears to be based on an analysis by Sprengel in 1826 where he found humic acid (this, a leachate of peat) as 58% carbon, 40% oxygen and 2% hydrogen, which, nearly 200 years later, is comparable to modern humic acid vales ranging from 51 to 62% (Pribyl 2010).

In a critical appraisal of the OC to SOM conversion, Pribyl (2010) assessed over 480 studies and concluded that the empirical factor should actually be 1.97, which concurred with that obtained from theoretical calculations of 1.95 (SOM to OC conversion of 51.3%). This is supported in an earlier study by Navarro *et al.* (1993) on the relationship between organic matter and carbon of organic wastes where they reported a value for OC to SOM conversion of 1.957 (SOM to OC conversion of 51.1%) for plant residues (Navarro *et al.* 1993). Use of the conversion factor of 58% (1.724) is also questioned by Chatterjee *et al.* (2009) as soil type, sampling depth and the type of organic compounds in the soil, all make the use of a fixed factor value problematic.

Conversion factors

Several conversion factors/formulae are presented below. Note "*x*" in each conversion/formula denotes the LOI value. The "*y*" value denotes either TOC (or OC) or TC. LOI treatments vary across studies, there appears to be no basis of uniformity, rather individual interpretation of previous findings presented in the literature.

Ball (1964), in a study of non-calcareous soils (mainly loams) from North Wales (England), applied two different LOI treatments, one of 375°C for 16 hours on 65 samples, with no correlation provided (Equation 5.b), the other of 850°C on 67 samples, recorded a correlation of $r^2 = 0.99$ (Equation 5.c). Ball's (1964) conversion of each LOI treatment was based on organic carbon analysis using Tinsley's (1950) modified Walkley and Black procedure (Ball 1964, p. 84). Both conversions were weighted to correct for proportionality due to higher results at lower LOI values.

$$y\ (\text{TOC}) = 0.458x - 0.40 \text{ (based on LOI at 375°C)} \quad 5.b$$

$$y\ (\text{TOC}) = 0.476x - 1.87 \text{ (based on LOI850)} \quad 5.c$$

Nixon (1980a) conducted a review of 20 years of coastal saltmarsh research where he quoted a conversion of LOI to carbon (it is not clear if this refers to organic carbon or total carbon, although he does refer to organic carbon later in the same paragraph) as 45% (p. 452), (OC to SOM conversion of 2.22). Nixon did not reference nor state the origin of this conversion value (Equation 5.d). Later work by Craft *et al.* (1988) used this conversion in a study on organic carbon pools in natural and transplanted coastal marshes of North Carolina (USA).

$$y\ (\text{TOC/TC}) = (0.45x) \text{ (based on LOI at unknown value)} \quad 5.d$$

Howard and Howard (1990) report on work conducted on soil samples from the English Lake District where analysis of 281 samples by LOI550 for 3 hours and carbon determination by dry combustion (analysis type not reported) generated a formula for conversion of LOI to organic carbon with a correlation of $r^2 = 0.98$ (Equation 5.e). They report that very few soils contained measurable amounts of inorganic carbon, therefore suggesting the total carbon (from dry combustion) was probably equivalent to organic carbon.

$$y\ (\text{TOC/TC}) = (x - 3.627)/1.670 \text{ (based on LOI550)} \quad 5.e$$

A study by Craft *et al.* (1991) assessed 250 soil samples from 10 salt and brackish-water marshes of North Carolina (USA) for SOM by LOI. The same samples were analysed for OC and total carbon (TC) using a Perkin-Elmer CHN analyser. Using regression analysis, they recorded a correlation of $r^2 = 0.99$, and derived the relationship between organic carbon and organic matter in the quadratic equation as follows (Equation 5.f):

$$y\ (\text{TOC}) = (0.40 \pm 0.01)x + (0.0025 \pm 0.0003)x^2 \text{ (based on LOI at 480°C)} \quad 5.f$$

A study by Navarro *et al.* (1993) of the relationship between organic matter and carbon contents of 38 plant waste samples involved LOI treatments at 430 and 600°C, both for 24 hours. The carbon content was measured by elemental microanalysis and Walkley and Black method, all values were correlated and tested with highly significant results at >99%. From this a conversion from LOI to TOC was formulated (Equation 5.g):

$$y\ (\text{TOC}) = 0.51x + 0.48 \text{ (based on LOI at 430°C)} \quad 5.g$$

In a study on 255 soil samples from five separate MLRA (major land resource area) locations in the North Central US, Konen *et al.* (2002) concluded that there are strong linear relationships between OC an LOI. Predictive equations (5.h to 5.l) were derived for each location with r^2 ranging from 0.94 to 0.98. The authors determined that although LOI was less precise than that by LECO dry combustion (TC referred to as TOC by authors as non-calcareous samples were analysed in study), LOI was highly reproducible with a coefficient of variation (CV) of less than 5%. Although Konen *et al.* (2002) didn't investigate the reasons for the differing calculations, they speculated that varying soil organic matter composition along with clay mineralogy and content were responsible.

$$y\ (\text{OC}) = 1.1414x - 0.6791 \text{ (MLRA 65, based on LOI at 360°C)} \quad 5.h$$

$$y\ (\text{OC}) = 0.6717x - 4.539 \text{ (MLRA 75, based on LOI at 360°C)} \quad 5.i$$

$$y\ (\text{OC}) = 0.5743x + 0.1025 \text{ (MLRA 95B, based on LOI at 360°C)} \quad 5.j$$

$$y\ (\text{OC}) = 0.6284x - 2.8696 \text{ (MLRA 103, based on LOI at 360°C)} \quad 5.k$$

$$y\ (\text{OC}) = 0.6094x - 0.1949 \text{ (MLRA 108, based on LOI at 360°C)} \quad 5.l$$

Analysis of 121 samples from boreal forests of Quebec (Canada) by LOI550 (overnight) and LECO dry combustion formulated a highly correlated ($r^2 = 0.97$) conversion (Equation 5.m), this study conducted by Perie and Ouimet (2008). Total carbon was assumed to equal OC, as inorganic carbon was either not present or seldom present in the non-calcareous samples.

$$y\ (\text{OC/TC}) = 0.4724x \text{ (based on LOI550)} \quad 5.m$$

Callaway *et al.* (2012) conducted a study on natural and restored wetlands in the San Francisco Bay estuary and explored the relationship between LOI/SOM and carbon.

LOI was conducted at 450°C for 8 hours with subsequent dry combustion analysis using a Flash 2000 Organic Elemental analyser. They established a very strong correlation between SOM and carbon ($r^2 = 0.99$), and from this formulated a quadratic regression to calculate carbon (Equation 5.n).

$$y\ (\text{OC}) = 0.3839x + (0.001217)x^2 \text{ (based on LOI at 450°C)} \qquad 5.n$$

A study by Owers *et al.* (2016) of just one location – Currambene Creek, NSW – found that the carbon content from dry combustion (continuous flow isotope ratio mass spectrometry) was significantly different from quantitative estimates to that of established conversions equations, for example Craft *et al.* (1991). For this site, they developed a conversion formula ($r^2 = 0.98$) based on the known value of LOI from Ball's (1964) method for a herbs, grasses and sedges saltmarsh (Equation 5.o).

$$y\ (\text{TC}) = 0.5606x + 0.0568 \text{ (based on LOI at 375°C)} \qquad 5.o$$

The author (Aalders) used unpublished data from a separate study (2014) on Tasmanian saltmarsh soils to develop conversions from LOI to TC. The study, in Tasmania's largest single saltmarsh at Long Point on the east coast (Aalders 2014), measured LOI550 and LOI850 each ashed for 3 hours from 34 plots (the soil organic layer considered to be the growing medium – where plant roots are found). The soils were classed as non-calcareous (they had failed the "fizz" test). Total carbon was measured on an ELTRA CS 2000 analyser for the same plots. Two conversions were formulated, one LOI550 to TC realised a correlation of $r^2 = 0.97$ (Equation 5.p), the other, LOI850 to TC achieved a correlation of $r^2 = 0.96$ (Equation 5.q).

$$y\ (\text{TC}) = 0.4571x - 0.6504 \text{ (based on LOI550)} \qquad 5.p$$

$$y\ (\text{TC}) = 0.4206x - 0.7133 \text{ (based on LOI850)} \qquad 5.q$$

The above conversions (Equations 5.b to 5.q) demonstrate the high variability in determining carbon content and the vagaries of individual study sites. It also emphasises how difficult it has become to use a conversion formula from another study with confidence.

Applications of conversions/formulae in other studies

There is evidence in the literature of studies that have used just two conversions from the above list to estimate organic/total carbon of saltmarsh soils.

Craft *et al.* (1988) used the conversion (Equation 5.d) from Nixon (1980b) in an investigation on carbon pools in coastal marshes.

Chmura *et al.* (2003) used the conversion developed by Craft *et al.* (1991) (Equation 5.f) to determine the global carbon sequestration of tidal, saline wetlands and applied the carbon value to soil bulk density values to determine an outcome. Keller *et al.* (2012) used the same conversion (Equation 5.f) to estimate OC storage in restored saltmarshes of Huntington Beach, California (USA); Ouyang and Lee (2014), in an update of global carbon accumulation rates of Chmura *et al.* (2003), referred to the conversion formulated by Craft *et al.* (1991); Macreadie *et al.* (2013) applied the same conversion (Equation 5.f) to LOI (525^{o}C for 3 hours) soil values to determine coastal marsh carbon loss following disturbance, and in a later analysis of sediments in a realigned saltmarsh in the Bay of Fundy (New Brunswick, Canada), Wollenberg *et al.* (2018) employed the same conversion following an LOI treatment of 350^{o}C for one hour, followed by 550^{o}C for 4 hours. From the literature, it appears that the Craft *et al.* (1991) conversion is acceptable to many workers. However, has this conversion been tested, not only for coastal saltmarshes as an overall generic conversion, but for individual vegetation classes? Even without laboratory testing, field observations clearly indicate a difference in soil organic matter content within individual vegetation groups and between vegetation groups.

In conclusion, Pribyl (2010) recommends the use of a factor of 2 in converting TOC to SOM (or $y = 0.50x$ when converting SOM to TOC), although he does provide a caveat to this as "the carbon content of soils is too variable for a single conversion factor, universally applied and based on questionable assumptions, to provide sufficiently reliable accuracy for reporting the quantity of soil organic carbon" (Pribyl 2010, p. 81).

Footnote: a search through the current literature has found that more often now, total carbon values are measured by direct dry combustion methods (e.g. LECO analysis) (Howe *et al.* 2009; Kelleway *et al.* 2016a; Macreadie *et al.* 2017; Lewis *et al.* 2018) rather than by LOI and applying a conversion. However, this comes at a high cost. Many

projects experience shortfalls in adequate funding (as did this study), and carbon determination of soils via LOI is still an important measure provided care is taken (Heiri *et al.* 2001), as costs to conduct this method are far lower than those by dry combustion methods.

Determination of conversion factor for Tasmanian coastal saltmarsh soils

During a state-wide preliminary survey of suitable sites *(n* = 21) for this study, three soil samples were collected from the organic layer of each plot *(n* = 110) along with three 10cm soil cores. The soil samples were dried in the laboratory, sieved on a 2mm screen, obvious plant material removed and three samples from each individual plot thoroughly mixed. Each soil sample was tested using the "fizz" or "champagne" method to determine the presence of carbonates (Craft *et al.* 1991; Kelleway *et al.* 2016b) by applying hydrochloric acid (HCl) to individual samples. No sample contained enough carbonate material to cause fizzing/bubbling, therefore it was presumed that all samples were non-calcareous (carbonate free). An LOI550 and LOI850 were carried out on each plot sample (see Section 5.2.1) with a subsequent analysis of total carbon by dry combustion (see Section 5.2.2 above). The total carbon value was deemed organic carbon as samples lacked carbonaceous material. This assumption follows earlier studies by Ball (1964), Howard and Howard (1990), Konen *et al.* (2002), Perie and Ouimet (2008) and Aalders (2014). The three soil cores for each plot were used to determine soil bulk density (see Chapter 4, Section 4.2.3 for method); the mean was calculated from each set of three cores from each plot, which became the SBD for that plot. The results were charted, TOC versus LOI550 and LOI850, and generic conversions generated. Subsequently, the dataset was sorted by vegetation community and individual charts produced, TOC versus LOI550, and individual conversions generated each representing a single vegetation community.

A selection from the above literature conversions of LOI to TOC/TC and the two conversions (from LOI550 and LOI850) generated from the preliminary sites were applied to the individual LOI550 and LOI850 plot values of the Combined data (Training, Test 1 and Test 2) plots *(n* = 407) from this study. The soils analysed in the study were classed as being non-calcareous as the differences between LOI850 and LOI550 values were very low (mean, standard error, 3.44 ± 0.17). Additionally, very few samples *(n* = 11) exhibited shell fragments and in over 95% of the samples, pH

values were <7.50 (mean, SE, 6.24 ± 0.04), an indication of non-calcareous soils (Macreadie *et al.* 2013).

5.2.4 Estimating carbon stock

It appears practice in some studies to equate organic carbon to total carbon for non-calcareous soils, for example, Ball (1964), Navarro *et al.* (1993), Baldock *et al.* (2014). As samples from this study have been deemed non-calcareous, this practice has been applied here.

To estimate carbon stock of coastal saltmarshes several parameters are required:

- Soil bulk density generally measured in grams per cubic centimetre;
- Total organic carbon in percentage terms;
- Mean organic layer depth of all plots expressed in centimetres (NB carbon assessment was made on the organic material in each plot, irrespective of the depth of the layer); and
- Total area generally measured in square kilometres.

Previous soil analysis determined individual values of bulk density and organic layer depth for each plot (Chapter 4). The determination of TOC for each plot was analysed in this section of the study. Total area of Tasmania coastal saltmarshes is available from Prahalad and Kirkpatrick (in press). Fortunately, area of succulent saltmarsh (classed as ASS under TASVEG) and graminoid saltmarsh (classed as ARS under TASVEG) has also been calculated by the same authors.

****

To establish the value of soil carbon density (SCD), the first two parameters are required – SCD is calculated as follows (Howe *et al.* 2009; Owers *et al.* 2016):

$$SCD\ (g/cm^3) = Bulk\ density\ (g/cm^3) \times TC(or\ OC)\% \quad (5.r)$$

Where:

SCD = soil carbon density, TC/OC = total carbon/organic carbon.

Example:

Bulk density = 0.50g/cm^3

TC (or OC) = 25%

SCD = 0.50g/cm^3 x 25%TC (or OC) = 0.125g of carbon/cm^3.

****

To calculate the carbon stock per hectare, two parameters are required – SCD and area.

Carbon stock can be expressed as Mg (megagrams) OC per hectare (Macreadie *et al.* 2017) as:

> Mg OC/ha, 0.01m (depth) = [SCD (g/cm^3) x 1 ha (in cm^2)]/1,000,000 (5.s)
>
> Where:
>
> Mg OC/ha, 0.01m = megagrams of organic carbon per hectare to 0.01m depth, SCD = soil carbon density (expressed as g/cm^3); the divisor (1,000,000) converts grams to megagrams.

Example:

SCD = 0.125g/cm^3

1 hectare = 100,000,000cm^2

Mg OC/ha, 0.01m = 0.125g/cm^3 x (100,000,000cm^2 x 1cm)/1,000,000 = 12.50Mg OC/ha.

****

To establish the carbon stock of coastal saltmarshes, the total area in hectares and mean organic layer depth is required.

In this case, carbon stock is a product of carbon per hectare, total hectares of saltmarshes and mean organic layer depth of all plots:

> Mg OC/ha, 0.##m (mean) depth = (Mg OC/ha x ha x depth)/1,000,000 (5.t)
>
> Where:
>
> Mg OC/ha = megagrams of organic carbon per hectare, ha = area of marshes (expressed in hectares), 0.##m = mean depth of organic layer (in metres).

Example:

Mg OC/ha = 12.50Mg OC/ha

125 hectares = 12,500,000,000cm^2

Depth = 10cm

OC stock of 125 hectares of saltmarshes of a mean organic layer depth of 10cm:

Mg OC =12.50Mg OC/ha x 12,500,000,000cm^2 x 10cm = 125.00Mg OC/ha, 0.10m depth.

****

From results attained above, additional calculations can be made as follows:

- Carbon stock per hectare by mean organic layer depth for individual vegetation communities (those established in Chapter 3);
- Carbon stock per hectare by mean organic layer depth for TASVEG classes ASS and ARS, as each individual fine scale community can be aligned to either broad scale class;
- Carbon stock for Tasmanian coastal saltmarshes by totalling the carbon stock for the individual TASVEG class, ASS and ARS (can be used to check the generic calculation); and
- Carbon stock per hectare by mean organic layer depth for individual vegetation communities in different IMCRA regions.

5.2.5 Carbon stock variations by IMCRA region

The main dataset was sorted by IMCRA region, then by vegetation community. Individual community conversions were applied independently to respective plot values of LOI550, and carbon stock values attained for each of the eight communities by individual IMCRA region. This allowed comparisons to be drawn between similar vegetation communities to ascertain if comparable carbon stock values existed between different IMCRA regions by vegetation community.

Methods of data management, laboratory analysis of LOI and DC, statistical analysis are described below.

5.2.6 Data management

Observations in the main combined dataset were reduced to attributes required for LOI/carbon analysis; they included: plot, site, fine scale vegetation code, IMCRA region, soil bulk density, organic layer depth, LOI550, LOI850. Additional columns were added to account for appropriate LOI conversions to carbon (that is using vegetation and coastal saltmarsh studies only) from Nixon (1980b), Craft *et al.* (1991), Navarro *et al.* (1993), Owers *et al.* (2016), Aalders (2014) (unpublished data).

Additionally, for the sake of completeness, conversions from Wolff (1864) (soil type = peat, which is a primary coastal saltmarsh soil type in Tasmania) referred to as the "Bemmelen factor", and Pribyl (2010) (this a generic value proposed for all soil types) were included.

5.3 Statistical analysis

5.3.1 Conversion from LOI to carbon

Generic conversion

The preliminary sites plots total carbon values from dry combustion were aligned to samples and two conversion formulae (TOC/LOI550 and TOC/LOI850) and correlations were determined for the preliminary sites plots. These generic conversions were then applied to the Combined sites plots and resulting values compared to literature conversions.

Individual community conversions

The TOC results for the preliminary sites plots were sorted by vegetation community (see Chapter 3). Conversion formulae were determined for each vegetation community (TOC/LOI550) and tested for strength of correlation. The individual vegetation community conversions were then applied to the Combined sites plots based on the designated vegetation community of each plot (this previously determined, see Chapter 3).

5.3.2 Carbon stock

Carbon stock of Tasmanian coastal saltmarshes can be calculated in a number of ways:

1. Mean of means, that is using a "global" mean calculated from the means of a range of values from a number of sites; for example, following the application of a generic conversion to all plots, the product of the mean soil bulk density and the mean organic carbon to determine the mean percentage of organic carbon over a range of sites; or, the product of the mean organic layer depth and the mean soil carbon density to determine carbon stock by volume;
2. Mean of individual values 1, that is the mean of predetermined individual values; for example, following application of a generic conversion to all plots – the

product of the mean of individual carbon density values and total area of saltmarsh; and

3. Mean of individual values 2, that is the mean of predetermined individual values; for example, following application of a specific vegetation community conversion to individual plots that have been identified as belonging to a predetermined vegetation community – the product of the mean of individual carbon density values, individual organic layer depths and total area of saltmarsh.

Estimation of the carbon stock was carried out in the following steps:

Mean of means – generic conversion

- Generic conversion applied to individual plot LOI550 values, this to determine carbon content;
- Mean soil bulk density and mean carbon content for all plots calculated;
- Mean soil carbon density calculated from Equation 5.r and applied to one hectare to calculate the mean carbon stock by hectare (on an area basis) (Equation 5.s);
- Mean carbon stock by hectare was applied to the total area of Tasmanian coastal saltmarshes (Prahalad & Kirkpatrick in press) to calculate the carbon stock by total saltmarsh area;
- Mean organic soil layer depth for all plots was calculated and applied to the carbon stock by total area (Equation 5.t) to obtain a generic carbon stock of Tasmanian coastal saltmarshes.

Mean of individual values 1 – generic conversion

- Generic conversion applied to individual plot LOI550 values, this to determine carbon content;
- Dataset sorted by vegetation group (determined in Chapter 3) and group means for bulk density, total carbon, and organic layer depth calculated by individual vegetation group (still using the generic conversion);
- Mean values (obtained above) were applied to Equations 5.r, 5.s and 5.t in turn to calculate the carbon stock for individual vegetation communities by hectare and by volume;

- Each vegetation community was aligned to either TASVEG vegetation class (ASS or ARS) and carbon stock by TASVEG vegetation class calculated by individual class area (Prahalad & Kirkpatrick in press); and
- Total carbon stock of Tasmanian coastal saltmarshes calculated by totalling the carbon stock for the individual TASVEG vegetation classes obtained above. This was compared to the generic totals (mean of means) obtained earlier.

Mean of individual values 2 – vegetation community conversions

- Dataset was sorted by vegetation group; each plot within each vegetation community was applied with appropriate conversion formula (that relative to that vegetation community) to determine carbon content;
- Individual plot soil carbon densities calculated, product of soil bulk density and carbon content (Equation 5.r) to determine carbon store by plot;
- Mean carbon store of all plots was applied to Equations 5.r, 5.s and 5.t in turn to calculate the carbon stock for individual vegetation communities by hectare and by volume;
- Each vegetation community was aligned to either TASVEG vegetation class (ASS or ARS) and carbon stock by TASVEG vegetation class calculated by individual class area (Prahalad & Kirkpatrick in press); and
- Total carbon stock of Tasmanian coastal saltmarshes calculated by totalling the carbon stock for the individual TASVEG vegetation classes obtained above. This was compared to the mean of means method generic conversion and mean of individual values generic conversion totals obtained earlier.

5.3.3 IMCRA regions and carbon stocks

The dataset was sorted by IMCRA region then by vegetation community. Individual community conversions were applied to individual plots within each region depending on the classification of each plot. Means were determined for carbon stock for each vegetation community within each region and results tabled. Subsequently, charts for each vegetation community were created to compare carbon density and carbon stock by region.

5.4 Results and discussion

The following section incorporates a combination of both results and discussion as some results require comment before progressing to a subsequent result. Within the following text, organic layer depth is expressed as cm (centimetres), soil bulk density and carbon density as g/cm^3 (grams per cubic centimetre), while organic carbon, LOI550 and LOI850 are expressed as % (percentage). All means are reported to standard error. Results have been comprehensively reported.

As soils in this study were considered non-calcareous (this based on the "fizz" test and complimentary data that showed carbonates were absent), the term organic carbon (OC), which can refer to total carbon (TC) as well as organic carbon, has been used in the following text. Furthermore, the terms vegetation community and vegetation group are also interchangeable.

5.4.1 Furnace tests and establishment of validity

Individual saltmarsh soil standards were analysed for LOI550 to validate the precision of the furnace. Tests resolved key elements that can impact LOI results: a) position in the furnace; b) size of the sample; and c) ashing period. Recorded data of each test are provided in the Appendix.

LOI tests – position in the oven

All standards were ashed as full runs, that is each run comprised one standard. One standard was replicated to check repeatability. Results are presented in Table 5.1 (and Appendix 5A.1).

Table 5.1: Furnace test results – position in the oven – 4 standards, one repeated, therefore 5 runs, all at 3 hours. Validated LOI = LOI550, Overall = all samples, irrespective of position in furnace, Column = all samples by column position (viewed north/south), Row = all samples by row position (viewed east/west). Results by mean and standard error.

		Furnace testing					
		Overall		Column		Row	
Standard	Validated LOI	Mean LOI (%)	CV (%)	Mean LOI (%)	CV (%)	Mean LOI (%)	CV (%)
1	50.6	50.53 ± 0.070	0.97	50.53 ± 0.074	0.94	50.53 ± 0.134	0.68
2	37.4	37.46 ± 0.049	0.91	37.46 ± 0.049	0.89	37.46 ± 0.074	0.75
3	12.6	12.99 ± 0.063	3.37	12.99 ± 0.061	3.31	12.99 ± 0.106	2.69
3 (repeat)	12.6	12.31 ± 0.041	2.34	12.31 ± 0.027	2.38	12.31 ± 0.041	2.26
5	10.7	10.61 ± 0.073	4.75	10.61 ± 0.032	4.90	10.61 ± 0.149	3.10

Results show that position in the oven, as overall, by column or by row, has little impact on standard error within each individual standard. All CV values are below 5% indicating high precision within the results. It is unclear as to why the CV values for Standards 3 and 5 (2.26 to 4.90%) are a lot higher than Standards 1 and 2 (0.68 to 0.97%). The LOI550 value for the Standards 3 and 5 (12.6 and 10.7% respectively) are significantly less than Standards 1 and 2 (50.6 and 37.4% respectively), indicating a higher mineral (sand) component to the sample, which may have an impact repeatability of testing. It was noted during subsequent LOI evaluations that samples exhibiting low LOI values often required more than 3 replicates to reduce the CV value to below 10% (this deemed when "enough is enough"). The LOI values for standards 1, 2 and 5 are acceptable in terms of the previously validated means (<0.1%); the LOI values for Standard 3 are within 3%, deemed satisfactory.

LOI tests – ashing time

Standard 2 was ashed at LOI550 for 2, 3, 4 and five hours to determine whether ashing intervals detrimentally affected results (Table 5.2, and Appendix 5A.2).

Table 5.2: Furnace test results – various ashing intervals for Standard 2 – 2, 3, 4, and 5 hours. Overall = all samples, irrespective of position in furnace, Column = all samples by column position (north/south), Row = all samples by row position (east/west). Results by mean and standard error.

		Furnace testing					
		Overall		Column		Row	
Standard & time	Validated LOI (%)	Mean LOI (%)	CV (%)	Mean LOI (%)	CV (%)	Mean LOI (%)	CV (%)
2 – 2hrs	37.4	37.36 ± 0.040	0.75	37.36 ± 0.026	0.76	37.36 ± 0.042	0.70
2 – 3hrs	37.4	37.46 ± 0.049	0.91	37.46 ± 0.049	0.89	37.46 ± 0.074	0.75
2 – 4hrs	37.4	38.18 ± 0.072	1.30	38.18 ± 0.055	1.31	38.18 ± 0.148	0.82
2 – 5hrs	37.4	38.37 ± 0.069	1.24	38.37 ± 0.054	1.25	38.37 ± 1.122	0.91

Increasing ashing time from 3 to 5 hours did increase the LOI value (~2.4%), however, as the difference between the validated value (at 3 hours) and the value attained following 5 hours of ashing was less than 1% (38.37 less 37.4), it was resolved to continue LOI treatment for 3 hours. The ashing period tests also showed no discernible effect from position in the furnace within and between runs.

LOI tests – sample weights

Weights of material within each sample was totally random, there was no effort made to maintain any uniformity in sample size. The means and standard errors were

calculated by individual weight brackets (0.5g units) for each LOI treatment of each standard. The results from the 3 hours repeat of Standard 2, and the 2, 4 and 5 hour repeats of Standard 3 were also included in this analysis (Table 5.3, see following page), and Appendix 5A.3).

This test demonstrates that sample weight is an important consideration in LOI treatment, as highlighted by Heiri *et al.* (2001). Smaller samples (by weight) lose greater weight (by percentage), than those samples having a higher weight at commencement of the LOI treatment. From Table 5.3 the recommended weight bracket appears to be in the 2.0 to 3.0g range.

The first two of the above tests have satisfied the validity of the furnace and generally dispelled any notions of differences relating to position in the furnace and period of ignition. However, sample size (weight) was identified as a matter requiring attention during sample preparation, it was resolved that weights be maintained in the 2 to 3g bracket.

5.4.2 Preliminary sites – LOI and dry combustion

Means, standard errors and ranges of LOI550 and LOI850, and means, standard errors and ranges of total carbon from dry combustion (this study) for all preliminary sites plots *(n* = 110) and individual vegetation communities are presented in Table 5.4 (see following page).

Table 5.3: Furnace test results – the impact of various sample weights for different standards. Weight range = 0.5g. Results by mean and standard error for each weight bracket. Results with "0.000" as standard error = 1 sample in weight bracket. Cells marked tan = nil sample within that weight bracket.

Standard	Validated LOI (%)	Sample weight bracket – mean and standard error within each weight bracket							
		1.01-1.5g	1.51-2.0g	2.01-2.5g	2.51-3.0g	3.01-3.5g	3.51-4.0g	4.01-4.5g	4.51-5.0g
1	50.6	50.78 ± 0.000	50.69 ± 0.218	50.78 ± 0.110	50.50 ± 0.138	50.27 ± 0.097			
2 (3hrs)	37.4	37.70 ± 0.184	37.49 ± 0.113	37.50 ± 0.088	37.31 ± 0.081	37.50 ± 0.083	37.15 ± 0.231	37.44 ± 0.393	
3	12.6	13.59 ± 0.000	13.61 ± 0.113	13.20 ± 0.138	12.89 ± 0.117	13.13 ± 0.218	12.95 ± 0.104	12.57 ± 0.134	12.74 ± 0.026
3 (repeat)	12.6			12.58 ± 0.285	12.30 ± 0.082	12.42 ± 0.063	12.20 ± 0.076	12.32 ± 0.135	12.05 ± 0.000
5	10.7	11.29 ± 0.000		10.99 ± 0.204	10.67 ± 0.216	10.75 ± 0.110	10.48 ± 0.128	10.57 ± 0.192	9.82 ± 0.169
2 (2hrs)	37.4	38.79 ± 0.362	38.27 ± 1.067	38.18 ± 0.137	38.22 ± 0.078	38.02 ± 0.142	38.06 ± 0.250		
2 (4hrs)	37.4	37.37 ± 0.071	37.41 ± 0.068	37.34 ± 0.080	37.12 ± 0.105				
2 (5hrs)	37.4	38.50 ± 0.141	38.26 ± 0.102	38.49 ± 0.092	37.95 ± 0.450				

Table 5.4: Preliminary sites data – means, standard errors and range for LOI550 and LOI850, and means, standard errors for total carbon by dry combustion, and number of plots. Vegetation communities are coloured to clusters grouped by numerical means of the carbon content – cluster 1, cluster 2, cluster 3 and cluster 4.

Vegetation community	LOI550			LOI850			Total carbon			
	Means	Min	Max	Means	Min	Max	Means	Min	Max	No. plots
All	29.19 ± 1.661	1.18	72.56	31.95 ± 1.739	2.30	75.65	**12.97** ± 0.757	0.28	31.60	110
AGH	15.49 ± 2.914	2.50	33.78	18.32 ± 3.373	2.77	44.56	**7.20** ± 1.328	1.16	16.44	13
AHM	31.45 ± 5.585	5.13	46.32	35.32 ± 6.007	6.32	52.54	**14.37** ± 2.587	1.23	21.77	8
AHR	36.55 ± 5.214	3.71	69.82	38.76 ± 5.316	6.92	72.79	**16.15** ± 2.343	2.05	31.60	15
AJK	32.71 ± 4.133	2.43	72.56	35.69 ± 4.323	4.46	75.65	**14.00** ± 1.849	0.39	31.36	21
AQR	23.34 ± 4.384	4.01	47.97	26.76 ± 4.486	5.77	54.37	**11.45** ± 1.963	1.73	21.16	11
ARH	34.10 ± 4.177	5.50	63.00	36.44 ± 4.270	6.91	67.32	**14.97** ± 1.882	2.37	28.76	15
ASH	19.01 ± 3.736	3.99	42.15	20.86 ± 3.594	5.51	42.73	**7.94** ± 1.255	1.22	16.24	10
ASQ	33.19 ± 4.057	1.18	53.68	36.06 ± 4.492	2.30	63.76	**14.85** ± 2.017	0.28	25.11	17

The vegetation communities can be segregated to four clusters numerically determined by the means of total carbon stored (see Table 5.4).

1. AGH (graminoids dominant over herbs) and ASH (*Tecticornia arbuscula* dominant over herbs) displayed carbon content mean (%) of 7.57 ± 1.225;
2. AQR (*S. quinqueflora*/*S. repens* dominated) exhibited a carbon mean (%) of 11.45 ± 1.963;
3. AHM (dominated by herbs), AJK (*Juncus kraussii* dominated), ARH (dominated by rushes over herbs) and ASQ (*Sarcocornia quinqueflora* dominated) displayed a carbon content mean (%) of 14.55 ± 2.038; and
4. AHR (herbs dominated over rushes) exhibited a carbon mean (%) of 16.15 ± 2.343.

Interestingly, clusters 1 and 3 (above) either contained vegetation communities that were not conjoined in the landscape or were structurally opposed. In cluster 1, AGH is positioned at the interface between saltmarsh and terrestrial communities, while ASH is found generally one community landward of the marine interface. Yet, the carbon content of both communities is similar. In cluster 3, AJK comprises tall rushes as a single community, ASQ comprises a low spreading succulent herb as a single community, yet both communities can be, and often are, found at the marine waters-saltmarsh interface. Again, both exhibit similar carbon content. Also, both vegetation communities are regarded as pioneer communities, and are often found as single communities in emerging marsh lands.

5.4.3 Conversion from LOI to carbon

Preliminary sites – generic conversion formulae

Dry combustion results were aligned to individual preliminary sites plots and charted against LOI values (LOI550 – Figure 5.3, LOI850 – Figure 5.4).

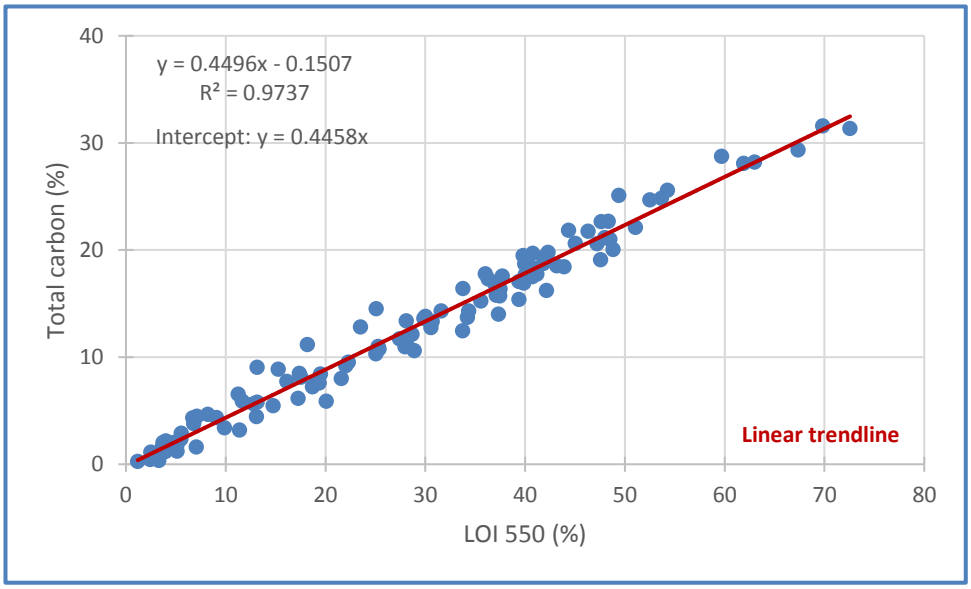

Figure 5.3: LOI550 against total carbon (by dry combustion).

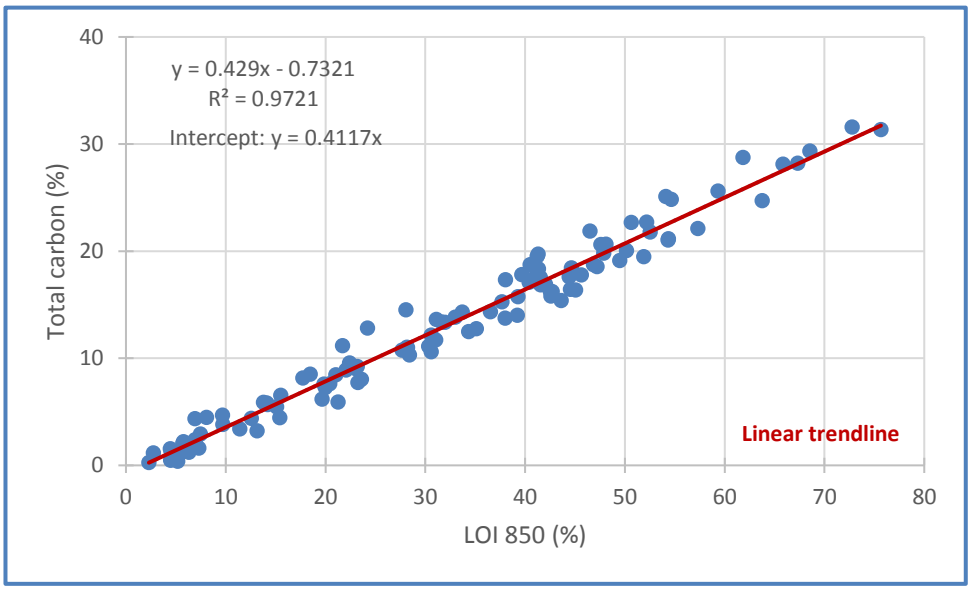

Figure 5.4: LOI850 against total carbon (by dry combustion).

Proposed generic LOI550 and LOI850 conversion formulae to total carbon are presented in Table 5.5 along with correlation coefficient for each LOI treatment.

Table 5.5: Proposed generic conversion formulae and correlation coefficient for each LOI treatment.

LOI treatment	Conversion formulae	Correlation coefficient (r^2)
LOI550	$y = 0.4496x - 0.1507$	0.9737
LOI850	$y = 0.4290x - 0.7321$	0.9721

Where: y = total carbon value (%), x = LOI value (%).

Comparison of proposed conversion formulae – generic

Conversions by Wolff (1864), Ball (1964), Nixon (1980b), Craft *et al.* (1991), Navarro *et al.* (1993), Pribyl (2010), Owers *et al.* (2016) and Aalders (2014) were aligned to the LOI550 and LOI850 values of all plots (n = 407). The generic conversion formulae (that from this study) were aligned to all plots and results were compared to literature conversions by way of means (Table 5.6).

Table 5.6: Individual literature conversions (x 8) and generic conversion from this study based on preliminary sites plots. Literature conversion formulae were applied to both LOI treatments, formulae from Ball (1964), Aalders (2014) and this study were applied to individual LOI treatments. Results means and standard errors. Blank cells due to conversions (Ball (1964), Aalders (2014) and this study) being specific to either LOI375/550 or LOI850. Means and standard error.

Author	Conversion	LOI550/TOC mean	LOI850/TOC mean
Wolff (1864)	$y = 0.5800x$	16.27 ± 0.527	18.27 ± 0.553
Ball (1964) LOI375	$y = 0.4580x - 0.4000$	12.45 ± 0.416	
Ball (1964) LOI850	$y = 0.4760x - 1.8700$		13.12 ± 0.454
Nixon (1980b)	$y = 0.4500x$	12.62 ± 0.409	14.17 ± 0.429
Craft *et al.* (1991)	$y = (0.40)x + (0.0025)x^2$	14.03 ± 0.509	16.00 ± 0.547
Navarro *et al.* (1993)	$y = 0.5100x + 0.4800$	14.79 ± 0.464	16.54 ± 0.487
Pribyl (2010)	$y = 0.5000x$	14.03 ± 0.455	15.75 ± 0.477
Owers *et al.* (2016)	$y = 0.5606x + 0.0568$	15.78 ± 0.510	17.71 ± 0.535
Aalders (2014) at LOI550	$y = 0.4715x - 0.6504$	12.17 ± 0.416	
Aalders (2014) at LOI850	$y = 0.4206x - 0.7133$		12.53 ± 0.401
This study at LOI550	$y = 0.4496x - 0.1507$	12.46 ± 0.409	
This study at LOI850	$y = 0.4290x - 0.7321$		12.78 ± 0.409

Where: y = total carbon value (%), x = LOI value (%).

LOI550

Results from Ball (1964), Nixon (1980b), Aalders (2014) and this study are analogous (range 12.17 to 12.62, mean 12.43 ± 0.093), while those of Craft *et al.* (1991), Navarro *et al.* (1993) and Pribyl (2010) display similarity (range 14.03 to 14.79, mean 14.28 ± 0.253). Wolff's (1864) result (16.27 ± 0.527) can be discounted as his conversion has been disputed and considered too high (Pribyl 2010), and that of Owers *et al.* (2016) (15.78 ± 0.510) is in doubt as it is representative of a specific plant community and from only four plots. The conversion from Aalders (2014), although it represents one site (Tasmanian east coast), yet 34 plots, is closely aligned to the conversion generated by this study, which represents 21 sites from a Tasmanian state-wide assessment. Furthermore, the conversion from Nixon (1980) was successfully applied to saltmarsh soils, and the one from Ball (1964) is considered creditable as he

has considered the reweighting of his conversion to remove any doubts in respect of proportionality especially in lower LOI values. In a similar way, an argument could be made for the use of Craft/Navarro/Pribyl mean as Craft *et al.* (1991) has been based on soil from "salt and brackish-water marshes" (p. 175) though there is no reference to any plant species. The conversion proposed by Navarro *et al.* (1993) has been based on plant matter "crop residues, forestall wastes and by-products of the agro-food industry (p. 204) rather than soil, and the conversion from Pribyl (2010) is a generic recommendation, one that has been "based on the assumption that organic matter is 50% carbon" (p. 81). Pribyl (2010) concludes that "any factor used to convert organic carbon to organic matter is not a universal physical constant. The factor may be influenced by vegetation cover, organic matter composition, depth in profile, amount of organic matter and clay in the soil, and degree of decomposition, all of which might reflect real differences in the carbon content of organic matter" (p. 81). In summary, the conversion proposed in this study is considered the most relevant as it is based on local (Tasmanian) soils, fits with an earlier conversion by Aalders (2014), again on Tasmanian soils, has a meaningful association with a reweighted conversion (Ball 1964) prepared for non-calcareous soils, and fits with an earlier saltmarsh soils conversion from Nixon (1980). This study's conversion for LOI550 will be used from hereon.

LOI850

LOI850 can be treated in a similar manner as that of LOI550. The proposed conversions produce a higher value than that of LOI550, which is expected as this is represented by the higher values produced by the LOI850 treatment (generally higher temperature results in more material be lost during treatment). However, as the soils from preliminary sites are classed as non-calcareous (supported by the low mean of inorganic matter (2.06 $\pm$ 0.14), pH of <6.5 and passing the "fizz" test), the use of conversions from most authors (Table 5.6) produce carbon values that are too high. It is accepted that most authors generated conversions that should be applied to LOI550 rather than LOI850. The conversions from Ball (1964), Aalders (2014) and this study (12.81 $\pm$ 0.171) are more acceptable and properly reflect the low inorganic matter component of the samples. Additionally, strong similarity exists between Aalders (2014) and this study, both representing Tasmanian coastal saltmarsh soils. Hence, the conversion proposed for LOI850 will be applied hereon.

Preliminary sites – individual vegetation communities conversion formulae

Dry combustion results were aligned to individual vegetation communities' preliminary sites plots and charted against LOI550 values. Charts are presented by each of the eight individual vegetation communities (Figures 5.5 to 5.12). All charts are scaled to the same range for ease of comparison.

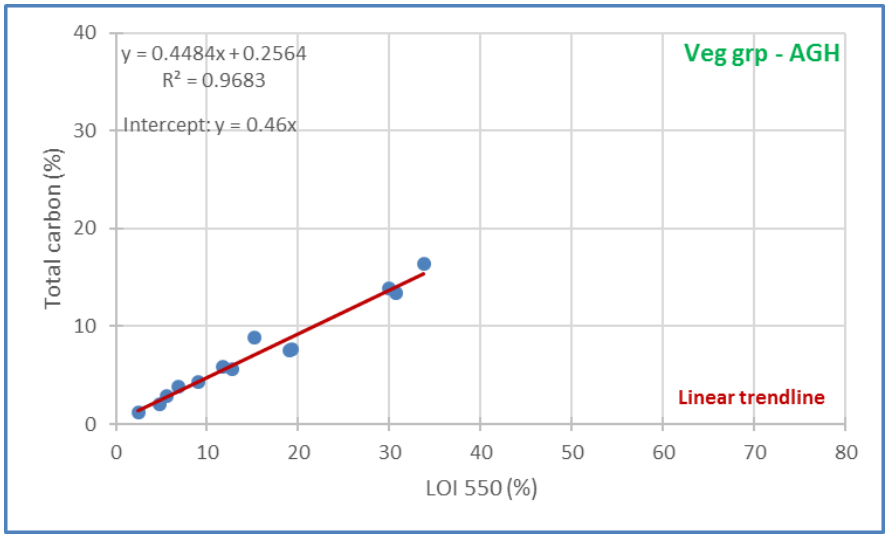

Figure 5.5: LOI550 against total carbon – vegetation community AGH.

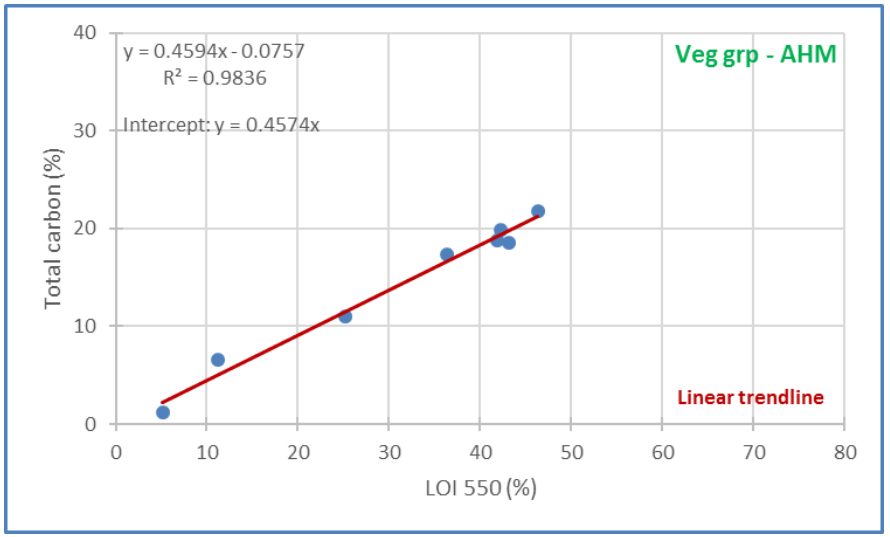

Figure 5.6: LOI550 against total carbon – vegetation community AHM.

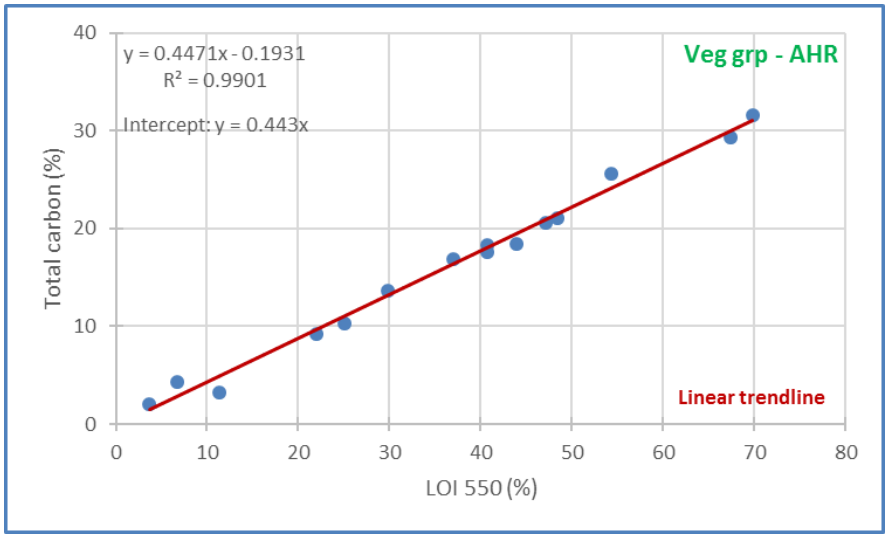

Figure 5.7: LOI550 against total carbon – vegetation community AHR.

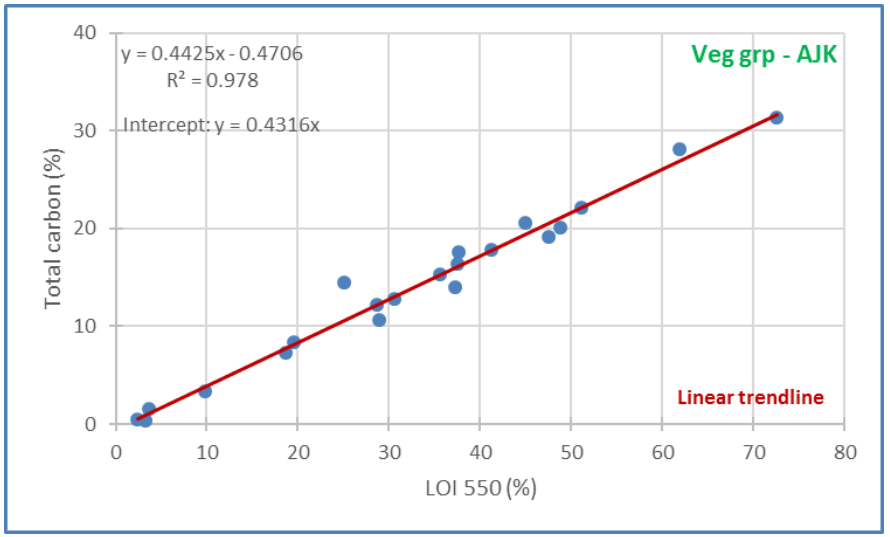

Figure 5.8: LOI550 against total carbon – vegetation community AJK.

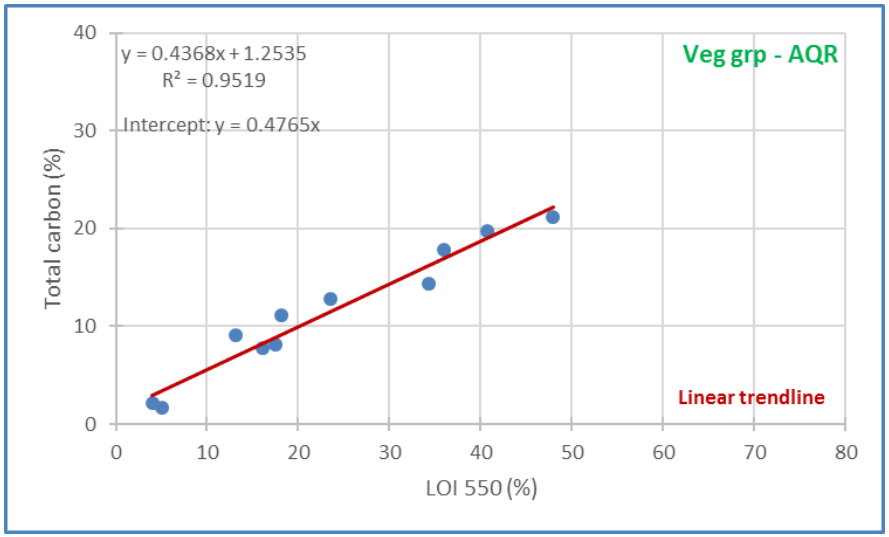

Figure 5.9: LOI550 against total carbon – vegetation community AQR.

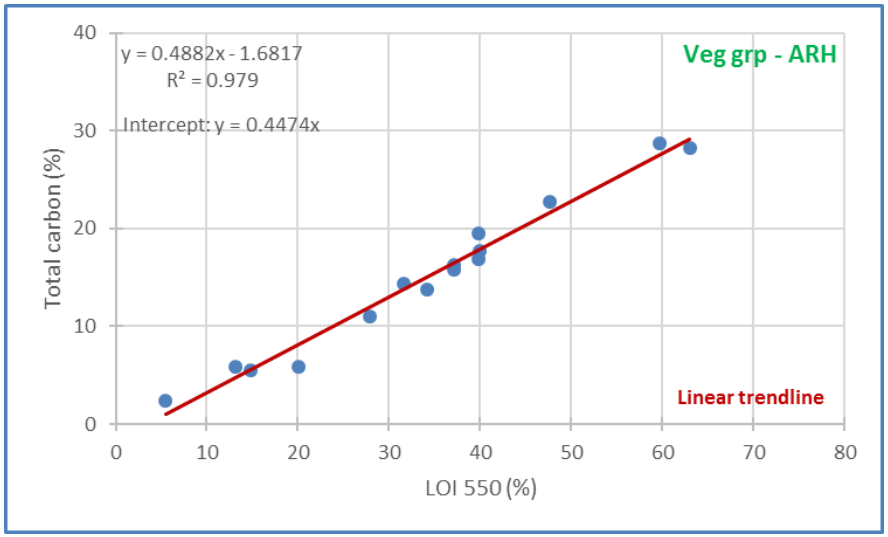

Figure 5.10: LOI550 against total carbon – vegetation community ARH.

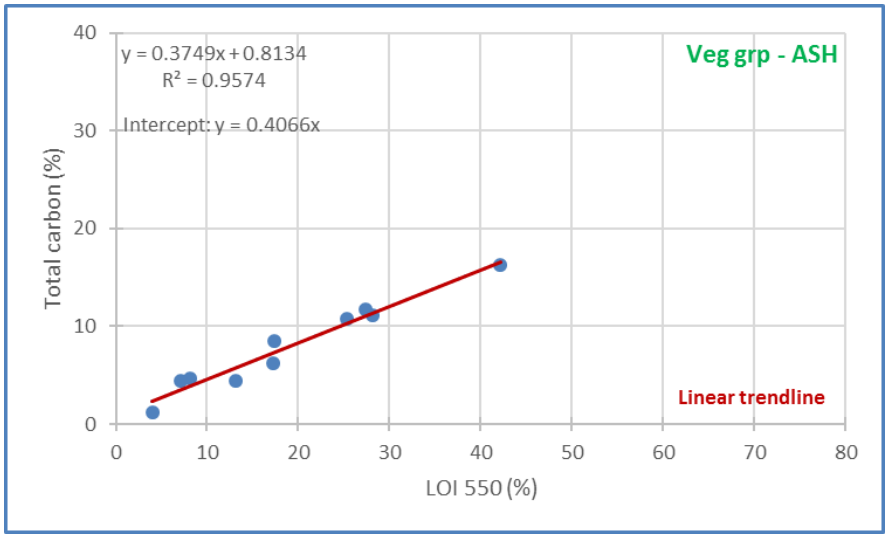

Figure 5.11: LOI550 against total carbon – vegetation community ASH.

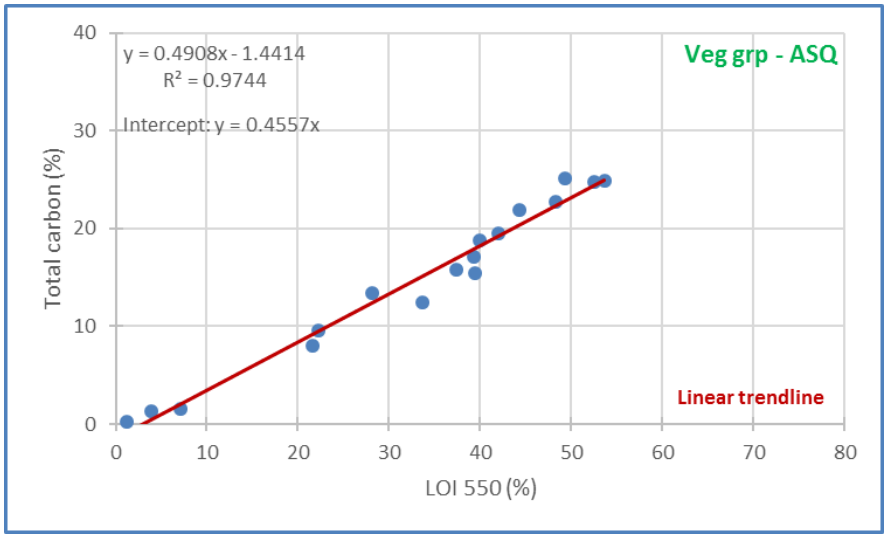

Figure 5.12: LOI550 against total carbon – vegetation community ASQ.

Conversion formulae – individual vegetation communities

Conversion formulae from LOI550 to TOC for individual vegetation communities (see Chapter 3) along with correlation coefficients are presented in Table 5.7, this based on non-calcareous soils.

Table 5.7: Conversion formulae from LOI550 to organic/total carbon for each individual vegetation community and correlation coefficient following LOI treatment. This based on non-calcareous soils. Generic conversion included for reference.

Vegetation community	LOI550 treatment	Correlation coefficient (r^2)
AGH	$y = 0.4484x + 0.2546$	0.9683
AHM	$y = 0.4594x - 0.0757$	0.9836
AHR	$y = 0.4471x - 0.1931$	0.9901
AJK	$y = 0.4425x - 0.4706$	0.9780
AQR	$y = 0.4368x + 1.2535$	0.9519
ARH	$y = 0.4882x - 1.6817$	0.9790
ASH	$y = 0.3749x + 0.8134$	0.9574
ASQ	$y = 0.4905x - 1.4414$	0.9744
Generic	$y = 0.4496x - 0.1507$	0.9737

Where: y = total carbon value (%), x = LOI value (%).

The slope (which represents the rate of change) on regressions can be segregated to three clusters. Vegetation communities AGH, AHM, AHR, AJK and AQR (and generic) all display a similar slope (0.4473 ± 0.0031); communities ARH and ASQ exhibit a comparable slope (0.4894 ± 0.0011), while the remaining community, ASH displays the weakest slope of 0.3749.

Comparison of proposed conversion formulae – individual communities

It is difficult to compare the proposed conversions by vegetation community with other studies as most do not provide information on plant species presence or cover. Owers *et al.* (2016) do provide a conversion (y (TC) $= 0.5606x + 0.0568$) for "herbs, grasses and sedges *(Sporobolus virginicus, Samolus repens, Sarcocornia quinqueflora)*" (p. 1298), which could be applied to four vegetation communities from this study (AGH, AHM, AHR and ARH) all of which could be described as herbs, grasses and sedges (note *S. virginicus* was not found in Tasmania). However, when Owers *et al.* (2016) conversion is applied to LOI550 values of the individual vegetation communities from this study the carbon content increases approximately 26% (Table 5.8).

Table 5.8: Application of conversions from this study and Owers *et al.* (2016) to vegetation communities that would fit the term "herbs, grasses and sedges", differences between OC values and percent differences. Individual conversions derived in this study applied to individual vegetation communities, while Owers *et al.* (2016) conversion applied to all communities.

Vegetation community	This study (%OC)	Owers (%OC)	Difference	% difference
AGH	10.05	12.77	2.72	27.1
AHM	12.85	16.27	3.42	26.6
AHR	15.69	19.81	4.12	26.3
ARH	14.84	18.74	3.90	26.3

The resulting differences between the two studies are excessive, strongly suggesting that the result of applying "a universal constant" (Pribyl 2010) to LOI values returns only an estimate of organic content and in this case can overvalue carbon content significantly. The difficulty with Owers *et al.* (2016) conversion is that it has been generated from one site using just two sediment cores. They critique their study and state that "failing to capture variation in vegetation structure can result in erroneous estimates of carbon storage…" (p. 1300) and acknowledge that their conversion is limited to their study site only.

Data from Aalders (2014) has been used to generate conversions for three vegetation communities, AGH, ASH and ASQ (the remaining communities were not present at the study site). The conversions were applied to the individual vegetation communities LOI550 data from this study and compared to results previously generated (Table 5.9).

Table 5.9: Application of conversions from this study to communities found in Aalders (2014) study, differences between OC values and percent differences. Individual conversions derived in this study and those of Aalders (2014) applied to individual vegetation communities.

Vegetation community	This study (%OC)	Aalders, 2014 (%OC)	Difference	Difference
AGH	10.05	9.72	0.33	3.1%
ASH	9.94	9.61	0.33	3.3%
ASQ	11.99	11.69	0.30	2.5%

The resulting differences between the two studies are small (<3.3%), suggesting that the current study conversions are appropriate as both studies represent Tasmanian coastal saltmarshes.

In light of the two comparisons examined above, it was deemed that the conversions for individual vegetation communities are appropriate.

Comparisons of carbon density – individual communities

Comparisons of sample depth (cm), carbon presence (%) and carbon density (g/cm^3) of individual vegetation (or plant species) communities can be made with several Australian studies which focus on the eastern and south-eastern coasts of the mainland (Queensland to Victoria) (*J. kraussii* – Table 5.10 and *S. quinqueflora* – Table 5.11). Although none of the studies provide a full list of plant species by presence and abundance it is worthwhile comparing results to this study.

Table 5.10: Comparison of *Juncus kraussii* saltmarsh studies of sample depth, carbon presence and soil carbon density. Studies by Saintilan *et al.* (2013) and Lovelock *et al.* (2014) are compared with comparable vegetation communities in this study. Results by mean and standard error. Note: Saintilan standard error values derived from reported standard deviation values. Depth values for this study are means of each individual vegetation community.

Study	Depth (cm)	Carbon (%)	Soil carbon density (g/cm^3)
Saintilan (Marra Marra)	30	24.0 ± 1.320	0.031 ± 0.006
Saintilan (Berowra Ck)	30	24.2 ± 1.414	0.028 ± 0.013
Lovelock	5	15.1 ± 3.000	0.050 ± 0.003
This study			
AJK	25	15.6 ± 1.482	0.061 ± 0.002
ARH	21	14.8 ± 1.234	0.053 ± 0.002

This study vegetation communities: AJK = *Juncus kraussii*; ARH = Rushes (including *Juncus kraussii* dominance) and herbs.

Saintilan *et al.* (2013) reported carbon content values 60% higher than those from Lovelock *et al.* (2014) and this study, yet soil carbon density values were 50% less than the two other studies. This indicates that soil bulk densities for both Marra Marra and Berowra Creek study sites (Saintilan *et al.* 2013) were very low (~0.125g/cm^3) compared to Lovelock *et al.* (2014) at 0.335g/cm^3, and 0.360g/cm^3 from this study. Although the soil carbon content of Lovelock *et al.* (2014) is very comparable to that of this study, care must be taken as they only sampled to 5cm, whereas this study's plots ranged in depth from 21 to 25cm (full organic layer). It appears likely that the presence of *J. kraussii* is not an indicator of high or low soil carbon density, and although marsh age was not a consideration of this study, nor is there any indication of the marsh age in the other studies, it may be an important factor for investigation in further studies. Some studies, for example, Wollenberg *et al.* (2018), have shown that new, restored and realigned marshes exhibit a lower carbon density value, this increasing over time, thus supporting the concept of marsh age being a factor of increasing carbon stock.

Table 5.11: Comparison of *Sarcocornia quinqueflora* saltmarsh studies of sample depth, carbon presence and soil carbon density. Studies by Howe *et al.* (2009), Saintilan *et al.* (2013) and Lovelock *et al.* (2014) are compared with comparable vegetation communities in this study. Results by mean and standard error (SE not available for Howe, 2009). Note: Saintilan standard error values derived from reported standard deviation values. Depth values for this study are means of each individual vegetation community.

Study	Depth (cm)	Carbon (%)	Soil carbon density (g/cm^3)
Howe (disturbed)	20	4.2 ± na	0.041 ± na
Howe (undisturbed)	20	9.0 ± na	0.065 ± na
Saintilan (Cararma Inlet)	30	24.4 ± 1.390	0.022 ± 0.002
Saintilan (Currambene Ck.)	30	25.3 ± 3.300	0.046 ± 0.006
Lovelock	5	2.2 ± 7.000	0.025 ± 0.001
This study			
ASQ	17	12.0 ± 0.831	0.056 ± 0.002
AQR	13	9.4 ± 1.579	0.050 ± 0.004
AHM	17	12.9 ± 0.969	0.058 ± 0.003
AHR	24	15.7 ± 1.524	0.063 ± 0.003

This study vegetation communities: ASQ = *Sarcocornia quinqueflora*; AQR = S*. quinqueflora* and *S. repens*; AHM = herbs mixed; AHR = herbs (dominance, including *Sarcocornia quinqueflora*) and rushes.

Saintilan *et al.* (2013) reported carbon content values 58% higher than the next highest value (15.7% from AHR, this study) and over 12-fold greater than the lowest recorded of that by Lovelock *et al.* (2014). Excluding the highest and lowest carbon value, there still exists an extended range (4.2 to 15.7%) for the remaining studies signifying a high diversity of *S. quinqueflora* between sites. Like that of *J. kraussii* discussed above, soil carbon density from Saintilan *et al.* (2013) Cararma Inlet study site, displays the lowest soil carbon density value (0.022 ± 0.002g/cm^3), this similar to that reported by Lovelock *et al.* (2014) (0.025 ± 0.001g/cm^3), with the undisturbed Howe *et al.* (2009) site and the AHR community from this study, displaying the highest carbon density values (0.065 and 0.063g/cm^3 respectively). As noted above for *J. kraussii*, it is apparent that *S. quinqueflora* is not an indicator of soil carbon density, other factors are at play for example, marsh age, depth of organic layer, soil bulk density.

5.4.4 Recommended conversion formulae

Generic

Recommended conversions of LOI treatments (LOI550 and LOI850) to organic/total carbon in Tasmanian coastal saltmarsh soils are presented in Table 5.12, this based on non-calcareous soils.

Table 5.12: Recommended conversions from LOI550 and LOI850 to organic/total carbon for Tasmanian coastal saltmarsh soils. This based on non-calcareous soils.

LOI treatment	Conversion
LOI550	$y = 0.4496x - 0.1507$
LOI850	$y = 0.4290x - 0.7321$

Where: y = total carbon value (%), x = LOI value (%).

Individual vegetation communities

Recommended conversions of LOI550 treatment to organic carbon in Tasmanian coastal saltmarsh soils in individual vegetation communities are presented in Table 5.13, this based on non-calcareous soils.

Table 5.13: Recommended conversion formulae from LOI550 to organic carbon for soils in each individual vegetation community from Tasmanian coastal saltmarshes. This based on non-calcareous soils.

Vegetation community	Conversion
AGH	$y = 0.4484x + 0.2546$
AHM	$y = 0.4594x - 0.0757$
AHR	$y = 0.4471x - 0.1931$
AJK	$y = 0.4425x - 0.4706$
AQR	$y = 0.4368x + 1.2535$
ARH	$y = 0.4882x - 1.6817$
ASH	$y = 0.3749x + 0.8134$
ASQ	$y = 0.4905x - 1.4414$

Where: y = total carbon value (%), x = LOI value (%).

The above conversions from LOI550 (only) have been used in the following sections.

5.4.5 Combined sites – LOI and carbon

Assumptions used in the following sections: all soils non-calcareous, LOI550 represents soil organic matter, which in turn can be converted to organic carbon.

Means of organic layer depth, soil bulk density, LOI550, estimated organic carbon (%) using recommended conversion formulae (above), for the Combined sites samples (n = 407) and individual vegetation communities are presented in Table 5.14 and displayed in Figures 5.13 to 5.16.

Table 5.14: Combined sites (all plots and individual vegetation communities), means of: O layer depth, soil bulk density (SBD), LOI550, percentage organic carbon, and number of plots in total and by vegetation community. Results by mean and standard error.

	Mean				No.
Veg group	Depth (cm)	SBD (g/cm3)	LOI550 (%)	OC (%)	plots
ALL	18.26 ± 0.563	0.466 ± 0.017	28.05 ± 0.909	12.46 ± 0.409	407
AGH	15.78 ± 1.219	0.613 ± 0.044	22.68 ± 2.234	10.05 ± 1.004	66
AHM	16.70 ± 1.219	0.450 ± 0.042	28.93 ± 2.156	12.85 ± 0.969	63
AHR	23.70 ± 2.136	0.401 ± 0.059	35.24 ± 3.389	15.69 ± 1.524	33
AJK	24.94 ± 2.412	0.392 ± 0.056	35.01 ± 3.296	15.59 ± 1.482	36
AQR	12.92 ± 2.147	0.535 ± 0.093	21.12 ± 3.513	9.35 ± 1.579	18
ARH	20.75 ± 1.638	0.356 ± 0.041	33.34 ± 2.746	14.84 ± 1.234	57
ASH	16.14 ± 1.360	0.491 ± 0.041	22.44 ± 2.007	9.94 ± 0.902	49
ASQ	17.06 ± 1.141	0.466 ± 0.037	27.01 ± 1.848	11.99 ± 0.831	85

Depth

Vegetation communities AJK and AHR displayed the greatest organic layer depth (24.94 ± 2.41 and 23.70 ± 2.14 respectively), the shallowest was community AQR (12.92 ± 2.15), while AGH, AHM, ASH and ASQ exhibited comparable depths (range 15.8-17.1).

SBD

Community AGH exhibited the heaviest soils (0.613 ± 0.044), followed by AQR (0.535 ± 0.093), while ARH had the lightest soils (0.356 ± 0.041).

LOI550

Vegetation communities AHR, AJK and ARH displayed similar levels of SOM (33 to 35), communities AHM and ASQ exhibited comparable amounts of organic matter (27-29), while AGH, AQR and ASH also displayed similar quantities of SOM (21-22).

OC

Vegetation community associations are a replicate of LOI550. Communities AHR, AJK and ARH displayed similar levels of OC (14.8 to 15.7), vegetation communities AHM and ASQ exhibited comparable amounts of organic matter (11.9-12.9), while AGH, AQR and ASH also displayed similar quantities of SOM (9.4-10.1).

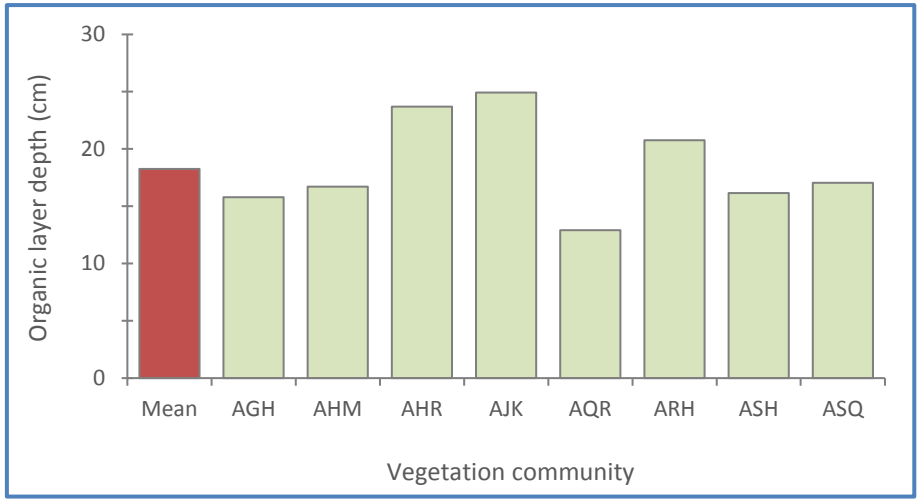

Figure 5.13: Mean/vegetation community and organic layer depth (cm).

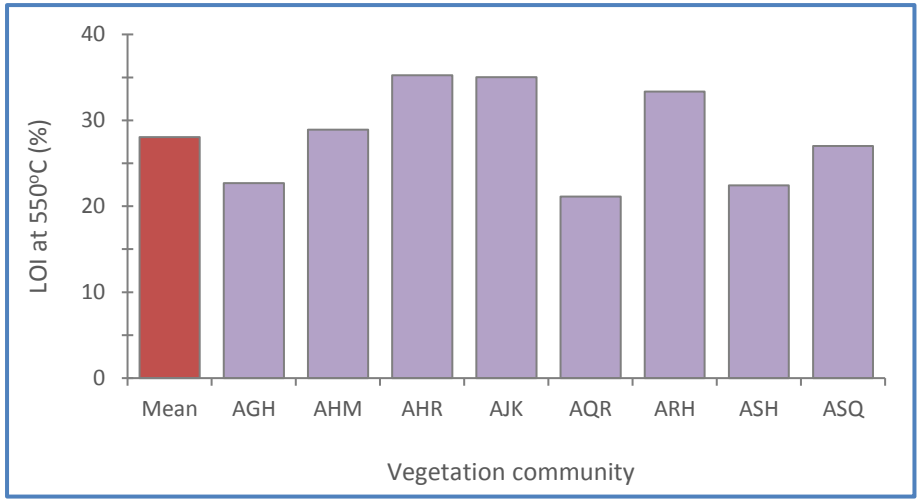

Figure 5.14: Mean/vegetation community and loss on ignition (%).

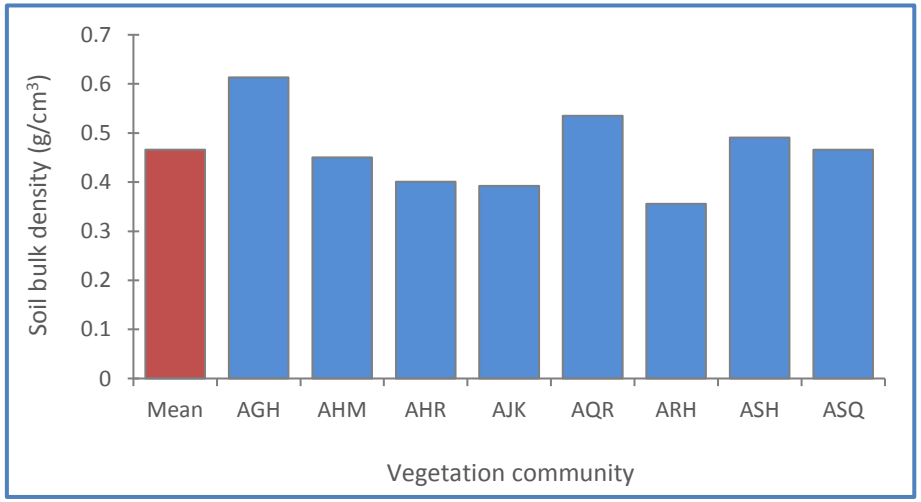

Figure 5.15: Mean/vegetation community and soil bulk density (g/cm^3).

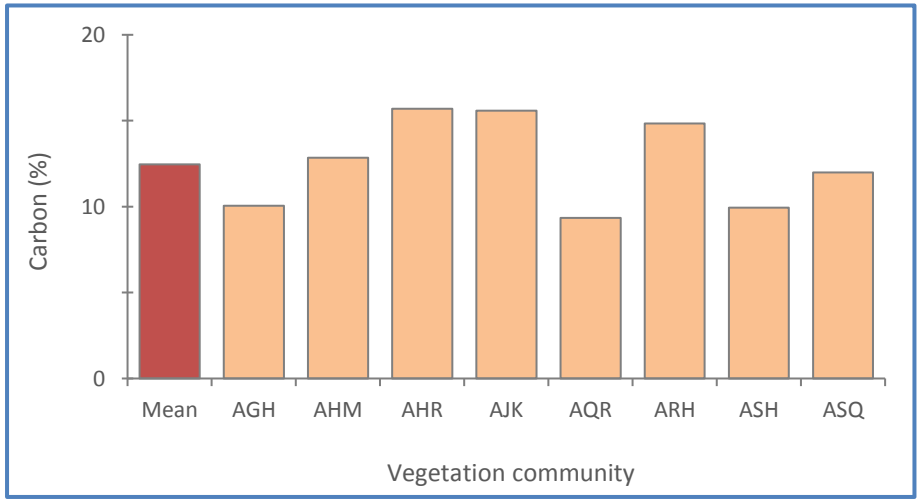

Figure 5.16: Mean/vegetation community and organic carbon (%).

5.4.6 Carbon stock

Carbon stock of Tasmanian coastal saltmarshes – mean of means method with generic conversion

A generic carbon stock value for Tasmanian coastal saltmarshes was calculated (Table 5.15), incorporating the mean of means method.

Table 5.15: Calculation of a generic carbon stock of Tasmanian coastal saltmarshes – mean of means method.

Calculation step	Results
Application of generic conversion to individual LOI550 values of each plot; organic carbon (%) = LOI550 * generic conversion	Individual plot value (%)
Mean carbon content of all plots (*n* = 407)	12.462%
Mean bulk density of all plots	0.466g/cm^3
Mean soil carbon density of all plots	0.058 g/cm^3
Mean carbon stock by area (per hectare)	5.811Mg OC/ha, 0.01m (depth)
Total area of Tasmanian coastal saltmarshes *	5,860ha
Generic carbon stock by saltmarsh area	34,049.75Mg OC, 0.01m
Mean organic layer depth of all plots	18.26cm
Generic carbon stock by saltmarsh volume	**621,638Mg** (or tonnes)

g/cm^3 = grams per cubic centimetre; cm = centimetre; Mg = megagram (= 1,000kg = 1 tonne); ha = hectare; Mg OC/ha = megagrams of organic carbon per hectare.

* Area (hectares) of coastal saltmarshes sourced from Prahalad and Kirkpatrick (in press).

Carbon stock of Tasmanian coastal saltmarshes – individual plot method 1 with generic conversion

A generic carbon stock value for Tasmanian coastal saltmarshes was calculated (Table 5.16), incorporating the individual plot method 1.

Table 5.16: Calculation of a generic carbon stock of Tasmanian coastal saltmarshes – individual plot method 1.

Calculation step	Results
Application of generic conversion to individual LOI550 values of each plot; organic carbon (%) = LOI550 * generic conversion	Individual plot value (%)
Determination of soil carbon density for each individual plot; soil carbon density = soil bulk density * organic carbon	Individual plot value (g/cm^3)
Mean of organic carbon density values of all plots (*n* = 407)	0.0369g/cm^3
Mean carbon stock by area (per hectare)	3.688Mg OC/ha, 0.01m (depth)
Total area of Tasmanian coastal saltmarshes *	5,860ha
Generic carbon stock by saltmarsh area	21,612.79Mg OC, 0.01m
Mean organic layer depth of all plots	18.26cm
Generic carbon stock by saltmarsh volume	**394,561Mg** (or tonnes)

g/cm^3 = grams per cubic centimetre; cm = centimetre; Mg = megagram (= 1,000kg = 1 tonne); ha = hectare; Mg OC/ha = megagrams of organic carbon per hectare.

* Area (hectares) of coastal saltmarshes sourced from Prahalad and Kirkpatrick (in press).

Carbon stock of Tasmanian coastal saltmarshes – individual plot method 2 with individual vegetation community conversions

A carbon stock value for Tasmanian coastal saltmarshes was calculated (Table 5.17), incorporating the individual plot method 2 with individual vegetation community conversions.

Table 5.17: Calculation of a carbon stock of Tasmanian coastal saltmarshes based on individual vegetation community conversions – individual plot method 2.

Calculation step	Results
Application of individual vegetation community conversions to individual LOI550 values of each plot (previously determined to vegetation community type); organic carbon (%) = LOI550 * generic conversion	Individual plot value (%)
Determination of organic carbon density for each individual plot; soil carbon density = product of soil bulk density * organic carbon	Individual plot value (g/cm^3)
Mean of organic carbon density values of all plots (*n* = 407)	0.0364g/cm^3
Mean carbon stock by area (per hectare)	3.645Mg OC/ha, 0.01m (depth)
Total area of Tasmanian coastal saltmarshes *	5,860ha
Generic carbon stock by saltmarsh area	21,358.31Mg OC, 0.01m
Mean organic layer depth of all plots	18.26cm
Generic carbon stock by saltmarsh volume	**389,934Mg** (or tonnes)

g/cm^3 = grams per cubic centimetre; cm = centimetre; Mg = megagram (= 1,000kg = 1 tonne); ha = hectare; Mg OC/ha = megagrams of organic carbon per hectare.

* Area (hectares) of coastal saltmarshes sourced from Prahalad and Kirkpatrick (in press).

So, which value is correct? The mean of means calculation (621,638 tonnes) is based on means of several factors without any consideration for variations within and between plots. It misses the complexities and relationships associated with individual plots, such as differences in organic layer depth and soil density, organic layer depth and LOI550, as correlations between these factors are very week (r^2 = ~0.36). When carbon stock values are calculated by use of the individual plot methods (generic conversion = 394,561 tonnes, and individual vegetation community conversion = 389,934 tonnes), the distinctions associated within and between plots are considered by determining organic carbon value (presence in percentage terms) and density (in weight terms) for each individual plot before any application of means. Here, individual plot intricacies are accounted for, and the collected data is used to its fullest extent. As the individual plot method is a more genuine approach and use of individual vegetation community conversions the most appropriate, the organic carbon stock of Tasmanian coastal saltmarshes is estimated to be 389,900 tonnes.

Economic value of carbon stored in Tasmania

The value of organic carbon stock in Tasmanian coastal saltmarshes has been estimated at $19.8 million (AUD) based on the average price per tonne (Mg) of CO_2-e at December 2018 auction by the Clean Energy Regulator (Australian Government – Emissions Reduction Fund) (http://www.cleanenergyregulator.gov.au/ERF/Auctions-results), which was $13.87. The value of carbon (C) in the CO_2 mix equates to 3.67 x $13.52 = $50.90 per Mg of C. The coastal saltmarsh carbon offset value can also be expressed as $3,380 per hectare, or 295 hectares per $1.0 million (AUD).

Comparison of carbon stock to other Australian jurisdictions

Data from published studies for Queensland (Qld) and New South Wales (NSW), along with data from CSIRO Coastal Carbon Cluster studies for Victoria (Vic), South Australia (SA) and Western Australia (WA) were used to determine carbon stocks on an Australian-wide basis (Macreadie *et al.* 2017). As Tasmania and the Northern Territory (NT) provided no data to the Macreadie *et al.* (2017) report, "the average organic carbon stock values of all Australian locations were used as a proxy in calculations" (p. 7) of carbon stocks. Jurisdictions of Qld, SA and WA had very low numbers of assessed sites (6, 3 and 4 respectively), with nil in NT, yet, three of the four jurisdictions, Qld (saltmarsh area 5,322km^2), WA (2,965km^2) and the NT (5,005km^2) represent over 96% of the total tidal marsh area of Australia (13,825km^2) (Macreadie *et al.* 2017). It is presumed that carbon stock data and results from the very small selection of individual State/Territory sites have been used to calculate a state-wide/continental value. This is somewhat troubling as Australian saltmarsh extent ranges approximately 4,000kms longitudinally and 3,800kms latitudinally, with climate zones of desert to subtropical longitudinally, and equatorial to temperate latitudinally (Bureau of Meteorology 2001). Obviously, climate (precipitation and temperature) will play a role in plant species presence and abundance and subsequent decay rates (Chmura *et al.* 2003), thus directly impacting carbon sequestration rates and ultimately carbon stocks. Therefore, results sourced from the literature have been taken at face value. Tasmanian values are those assessed by the individual plot method using vegetation community conversions in this study.

There is no uniformity in depth values, which makes it difficult to evaluate values on a State-by-State basis. NSW records to 20cm, other mainland States to 30cm, while

Tasmania's mean depth is 18.26cm, ranging from 0 to 45cm. For ease of comparison of carbon stock values (mean carbon stock by hectare), all values have been recalculated to 1cm (0.01m) depth, thus based on area (hectares). Organic carbon densities and stocks on a State-by-State basis are tabled in Table 5.18.

Table 5.18: Individual State saltmarsh comparisons of organic carbon, soil bulk density, organic carbon density and organic carbon stocks (values are mean and standard error). State data, except for Tasmania, sourced from Macreadie *et al.* (2017), carbon stock values recalculated to standard depth of 0.01m. Tasmania data calculated by use of individual plot method (vegetation community conversions). State order alphabetical. Note: no data available from NT.

State	Organic carbon (%)	Bulk density (g/cm^3)	Carbon density (g/cm^3)	Carbon stock per hectare (Mg OC/ha, 0.01m)	Number of sites
NSW	5.35 ± 0.49	0.92 ± 0.03	0.049 ± 0.002	4.922 ± 0.20	25
Qld	8.67 ± 2.17	0.73 ± 0.11	0.063 ± 0.010	6.329 ± 1.00	6
SA	6.78 ± 1.56	0.24 ± 0.12	0.016 ± 0.008	1.627 ± 0.80	3
Tas	7.87 ± 0.41	0.46 ± 0.03	0.036 ± 0.002	3.645 ± 0.15	91
Vic	7.86 ± 0.59	0.88 ± 0.04	0.069 ± 0.003	6.917 ± 0.30	45
WA	7.35 ± 1.80	0.30 ± 0.09	0.022 ± 0.007	2.205 ± 0.70	4

On a state by state basis, NSW has the lowest mean organic carbon by percentage (5.35 ± 0.49), the highest soil bulk density (0.92 ± 0.03g/cm^3), and a carbon stock of 4.922 ± 0.20Mg OC/ha, 0.01m (Macreadie *et al.* 2017). Tasmania on the other hand, has mid-range percent of organic carbon (7.87 ± 0.41), a mid-range soil bulk density (0.47 ± 0.02g/cm^3) and a carbon stock of 3.645 ± 0.15Mg OC/ha, 0.01m. This has placed Tasmania reasonably well in respect of accumulated carbon stocks per hectare of coastal saltmarshes (4th of those States surveyed). However, Tasmania's overall contribution to Australia's saltmarsh carbon stocks is relatively low due to the shallow depth of the marshes (18.26 ± 0.563cm) and its small spatial area of 5,860ha (Prahalad & Kirkpatrick in press), just 0.42% of Australia's total 1,382,500ha (Macreadie *et al.* 2017). Of all States surveyed, Tasmanian data has been sourced from 91 sites (407 plots), whereas the next best contribution of data came from Victoria (45 sites), followed by NSW (25 sites). Tasmania, the smallest of all Australian States and Territories, and smallest by area of coastal saltmarshes, yet with a coastline far greater than both Victoria and NSW (Geoscience Australia n.d.), has been the most extensively surveyed (this in a single study). For an improved comparison of nationwide organic carbon stocks in coastal saltmarshes, additional data should be sourced from Qld, SA, WA and the NT as these jurisdictions have contributed little in terms of site diversity and range. Furthermore, to avoid bias and skewed results (from too few sites), data

should be sourced from a wide range of coastal sites (Macreadie *et al.* 2017) that include various estuary types such as intermittently open and closed lagoons, drowned river valleys, marine inlets and embayments (see Chapter 1 – Estuarine classifications). This will provide, not only an updated current value, but a more comprehensive view of carbon stocks held in saltmarshes. What follows is a greater appreciation of coastal saltmarshes by government and the general public.

Carbon stock of individual vegetation communities

Following the procedure outlined in statistical analysis above (Section 5.3.2), individual carbon stock values were determined for each vegetation community (by use of individual plot method 2 – vegetation community conversions) (Figures 5.17 and 5.18), then aligned to the TASVEG saltmarsh vegetation class (Table 5.19).

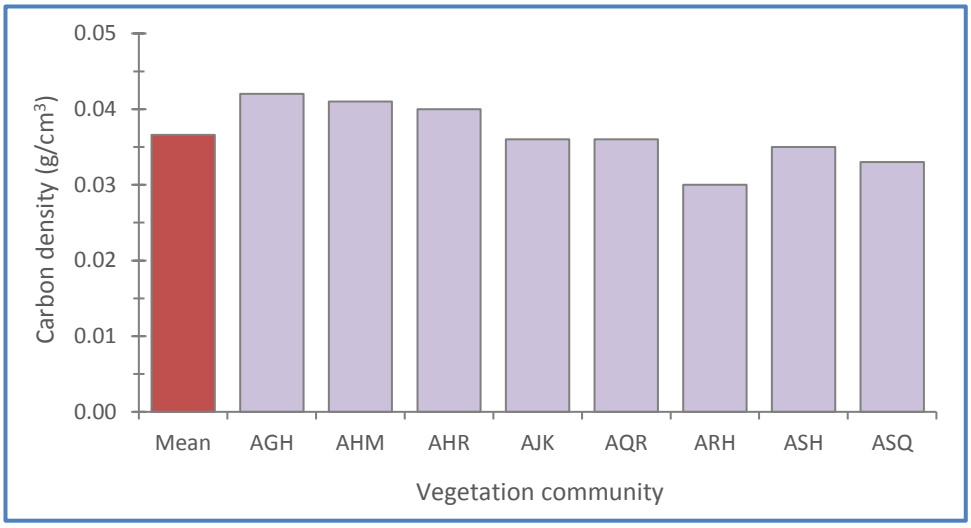

Figure 5.17: Mean and vegetation community soil carbon densities (g/cm^3).

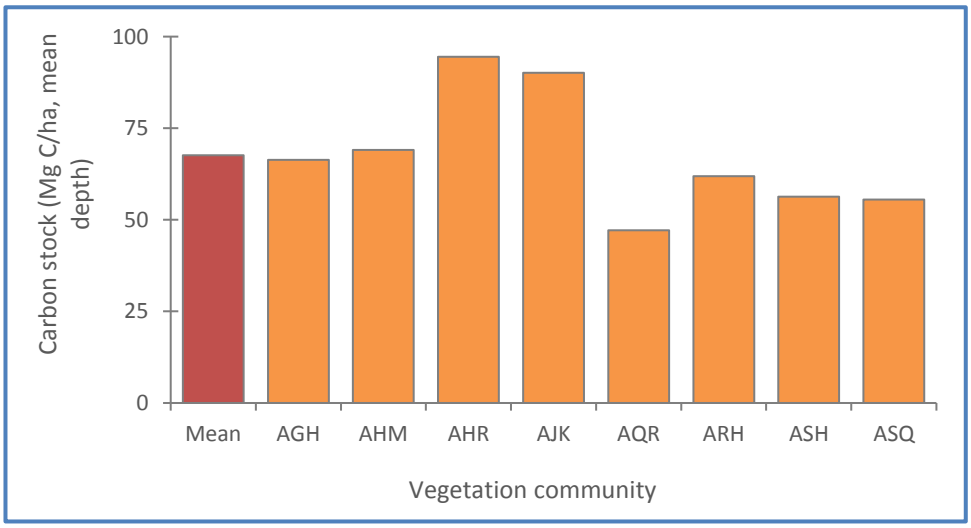

Figure 5.18: Mean and vegetation community carbon stocks (Mg OC/ha, mean depth individual community).

Table 5.19: Calculation of carbon stock by vegetation community (those determined in Chapter 3). Results by mean and standard error.

	Vegetation community							
Calculation step	**AGH**	**AHM**	**AHR**	**AJK**	**AQR**	**ARH**	**ASH**	**ASQ**
Mean bulk density (g/cm^3)	0.613 ± 0.044	0.450 ± 0.042	0.401 ± 0.059	0.392 ± 0.056	0.535 ± 0.093	0.356 ± 0.041	0.491 ± 0.041	0.466 ± 0.037
Mean carbon content (%)	6.870 ± 1.004	9.192 ± 0.969	9.944 ± 1.524	9.219 ± 1.482	6.825 ± 1.579	8.368 ± 1.234	7.102 ± 0.902	6.984 ± 0.831
Mean organic layer depth (cm)	15.78 ± 1.219	16.70 ± 1.219	23.70 ± 2.136	24.94 ± 2.412	12.92 ± 2.147	20.75 ± 1.638	16.14 ± 1.360	17.06 ± 1.141
Mean soil carbon density (g/cm^3)	0.042 ± 0.003	0.041 ± 0.003	0.040 ± 0.003	0.036 ± 0.002	0.036 ± 0.004	0.030 ± 0.002	0.035 ± 0.002	0.033 ± 0.002
Mean carbon stock by area (Mg OC/ha, 0.01m)	4.209 ± 0.272	4.139 ± 0.298	3.988 ± 0.345	3.610 ± 0.232	3.649 ± 0.369	2.980 ± 0.199	3.489 ± 0.278	3.256 ± 0.219
Mean carbon stock by volume (Mg OC/ha, mean depth of veg community)	**66.4 ± 0.055**	**69.1 ± 0.063**	**94.5 ± 0.147**	**90.1 ± 0.104**	**47.1 ± 0.091**	**61.9 ± 0.084**	**56.3 ± 0.046**	**55.5 ± 0.050**
Assignment to TASVEG vegetation class	ARS	ASS	ASS	ARS	ASS	ARS	ASS	ASS

g/cm^3 = grams per cubic centimetre; cm = centimetre; Mg = megagram (1,000kg = 1 tonne); ha = hectare; OC = organic carbon; Mg OC/ha = megagrams of organic carbon per hectare.

Mean organic carbon stock (Mg OC/ha, 0.01m) across all vegetation communities was not significantly different (3.665 ± 0.152), however, the total stock by volume (Mg OC/ha, mean depth) was significantly different (67.618 ± 5.901). Vegetation communities AJK (*Juncus kraussii* dominant) (90.04Mg OC/ha, mean depth) and AHR (herbs dominant over rushes) (94.51Mg OC/ha, mean depth) were ~37% greater than each of the remaining communities. Although both communities had a low mean bulk density (0.392 and 0.401g/cm^3 respectively) compared to the remainder, mean carbon content was highest (9.22 and 9.94% respectively), and organic layer depth greatest (24.94 and 23.70cm respectively). Observed from a field-based view, one would have expected communities AHM (mixed herbs) and ASQ (*Sarcocornia quinqueflora* dominant) to have contained the highest carbon stock. Both communities exhibited very high levels of peat in the organic layer, while communities such as AGH (graminoid dominant over herbs) and ASH (*Tecticornia arbuscula* dominant over herbs) exhibited higher levels of sand/silt over peat/loamy-soil in the organic layer. However, on reflection, AHM and ASQ communities displayed shallow organic depths (16.70 and 17.06cm respectively) and bulk density values (0.450 and 0.466g/cm^3) were midrange, both key features in carbon stock calculations. Owers *et al.* (2016) reported that rushes (e.g. *J. kraussii*) had the highest soil carbon content (1.84Mg OC/ha, 0.01m depth) of all saltmarsh and mixed ecotone communities (at Currambene Creek), followed by herbs, grasses and sedges (a similar community to AGH found in here) (1.39Mg OC/ha, 0.01m depth), both values far lower than those recorded in Tasmania.

Carbon stock calculation and values for ARS and ASS are presented in Table 5.20.

Table 5.20: Calculation of carbon stock by TASVEG vegetation class. Mean area (hectares) of individual vegetation class sourced from Prahalad and Kirkpatrick (in press).

Calculation step	ARS	ASS
Mean soil carbon density of assigned vegetation groups (g/cm^3)	0.036	0.037
Mean carbon stock by area (Mg OC/ha, 0.01m)	3.600	3.704
Mean organic layer depth (cm)	20.49	17.30
Mean carbon stock by volume (Mg OC/ha, mean depth of veg class)	**72.776**	**64.530**
Mean area of individual TASVEG vegetation class (ha)	2,520	3,340
Carbon stock by vegetation class by volume (Mg or tonnes)	183,370	215,529
Total (Mg or tonnes)	**398,899**	

Mg = megagram (1,000kg = 1 tonne); ha = hectare; Mg OC/ha = megagrams of organic carbon per hectare.

Based on a volumetric measurement (Mg OC/ha, mean depth of vegetation class), vegetation class ARS has a carbon stock 12.5% greater than that of ASS. However, as the spatial extent of ASS is 32.5% greater than ARS, the carbon stock of ASS is 17.5% higher than ARS.

The carbon store by TASVEG is 2.3% greater than that calculated by individual vegetation communities (see Table 17), which is an acceptable difference to the original calculation. The coastal saltmarsh carbon offset value can also be expressed as $3,377 per hectare, or 296 hectares per $1.0 million (AUD) which is similar to that obtained by a combination of all vegetation communities.

5.4.7 IMCRA regions and carbon stocks

Carbon density

Vegetation community by IMCRA region

Soil carbon density of individual vegetation communities by individual IMCRA regions are presented in Table 5.21. Note: vegetation communities that are present in four plots or less by region have been excluded in the following comments. This is justified as anything less than five plots would not be sufficiently representative of the vegetation community within an individual IMCRA region. This means that regions Flinders (total plots = 9) and Davey (total plots = 14) are not considered, as in both regions, all vegetation communities are present in four plots or less.

Table 5.21: Soil carbon density of vegetation communities by IMCRA regions.

	Boags		Bruny		Davey		Flinders		Franklin		Freycinet		Otway	
Veg Com	**Plots**	**Carbon g/cm³**	**Plots**	**Carbon g/cm³**	**Plots**	**Carbon g/cm³**	**Plots**	**Carbon g/cm³**	**Plots**	**Carbon g/cm³**	**Plots**	**Carbon g/cm³**	**Plots**	**Carbon g/cm³**
AGH	9	0.0548	24	0.0681	0		1	0.0858	5	0.0382	25	0.0521	2	0.0136
AHM	10	0.0560	22	0.0505	0		2	0.1048	6	0.0335	23	0.0572	0	
AHR	3	0.0795	16	0.0468	1	0.0417	1	0.0163	4	0.0581	7	0.0600	1	0.0214
AJK	8	0.0494	12	0.0583	9	0.0395	0		3	0.0208	4	0.0540	0	
AQR	3	0.0329	8	0.0453	0		1	0.0065	0		2	0.0287	4	0.0564
ARH	5	0.0461	25	0.0546	7	0.0341	2	0.0101	7	0.0285	8	0.0547	3	0.0472
ASH	8	0.0319	20	0.0460	0		2	0.0597	0		16	0.0528	3	0.0303
ASQ	16	0.0434	32	0.0515	0		0		4	0.0233	32	0.0555	1	0.0183
TOTAL	**62**		**159**		**17**		**9**		**29**		**117**		**14**	

= <5 plots per vegetation community

= nil plots in vegetation community

Of all IMCRA regions, Freycinet displays the highest soil carbon density (0.0552 ± 0.001) closely followed by Bruny (0.0527 ± 0.003), while Franklin displays the lowest (0.0338 ± 0.004). It is unclear why there is a ~38% difference between Freycinet/Bruny and Franklin. Position in the landscape may be a factor, as both Freycinet and Bruny adjoin and are on Tasmania's east coast (granite dominated geology, sheltered coastline, deeper soils), while Franklin is on the State's west coast (quartzite dominated geology, exposed coastline, shallower soils), or it may be simply that Franklin is represented by only three vegetation communities (total of 18 plots), whereas Bruny is represented by all vegetation communities (total 159 plots) and Freycinet by six communities (total of 111 plots). A clearer reason may be realised if an increased number of vegetation communities and plots were assessed in Franklin. However, this region is restricted in coastal saltmarsh diversity and there is a paucity of available sites, while the Freycinet/Bruny combination has a plethora of available sites. As a point of interest, if both Flinders and Otway were included, Flinders (0.0475 ± 0.032) would be positioned midway in the soil carbon density range of all vegetation communities, while Otway (0.0321 ± 0.014) would be at the lower (lighter) end of the range.

Means of each vegetation community across al IMCRA regions (excluding those with less than five plots by region) are presented in Table 5.22.

Table 5.22: Differences between soil carbon density by vegetation community across IMCRA regions. The value of *n* refers to vegetation community presence in number of regions.

Veg Com	Mean (g/cm^3)	Std Dev	*n*	Std Err	Max	Diff to mean	Min	Diff to mean
AGH	0.0556	0.0123	4	0.0061	0.0699	25.83%	0.0400	-27.99%
AHM	0.0508	0.0111	4	0.0055	0.0589	15.94%	0.0348	-31.50%
AHR	0.0530	0.0093	2	0.0065	0.0595	12.37%	0.0464	-12.37%
AJK	0.0472	0.0090	3	0.0052	0.0563	19.20%	0.0383	-18.91%
AQR								
ARH	0.0424	0.0138	5	0.0062	0.0545	28.60%	0.0266	-37.23%
ASH	0.0415	0.0085	3	0.0049	0.0498	19.90%	0.0329	-20.79%
ASQ	0.0485	0.0088	3	0.0051	0.0522	7.63%	0.0385	-20.62%

Again, vegetation communities that are present in four plots or less by region have been excluded in the following comments.

Vegetation community AGH exhibits the highest soil carbon density mean

(0.0556 ± 0.006) followed by AHR (0.0530 ± 0.007), while ASH exhibits the lowest carbon density (0.0415 ± 0.005) across all IMCRA regions. Community ARH displays the greatest range of soil carbon density values (0.0266-0.0545), while AHR displays the smallest range (0.0464-0.0595). Vegetation community AHR was only found in two regions, Bruny and Freycinet, while community ARH is found across most regions, albeit dominant in the Bruny region.

A comparison of the mean of all vegetation communities and mean of individual communities of soil carbon densities is presented in Figure 5.19.

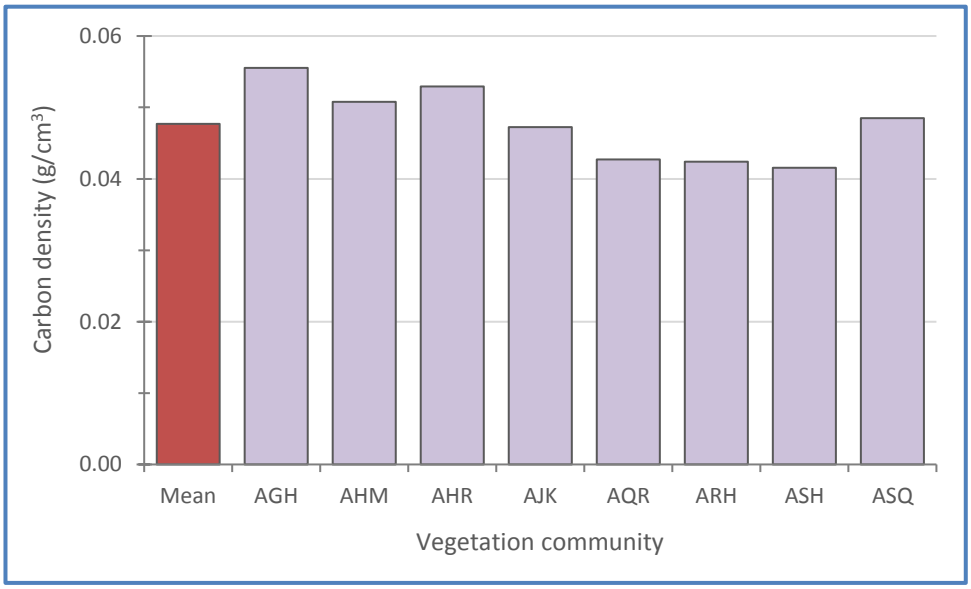

Figure 5.19: A comparison of overall mean and vegetation community means soil carbon densities (g/cm^3) across all IMCRA regions.

For a more informative illustration, all vegetation communities have been included in Figure 5.19 (above). Vegetation community AGH exhibits the highest soil carbon density across all IMCRA regions, while ASH displays the lowest value. Communities AQR (*S. quinqueflora* and *S. repens*), ARH (rushes dominant over herbs) and ASH exhibit similar means (0.042 ± 0.000), as do communities ASQ (*S. quinqueflora*) and AJK (*J. kraussii*) (0.048 ± 0.001), this noted in the study by Macreadie *et al.* (2017).

Soil carbon densities of individual vegetation communities by mean (of all regions) and IMCRA region are presented in Figures 5.20 to 5.27. A vegetation community that is represented by less than five plots within an IMCRA region is not included in the figures as not sufficiently representative of the community. All charts have similar scale range.

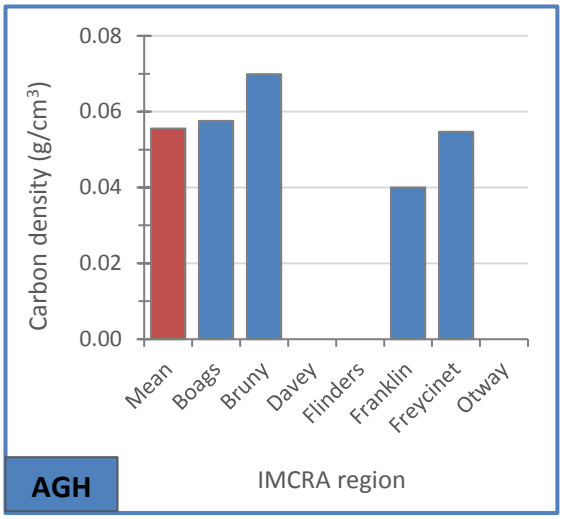

Figure 5.20: Carbon density of vegetation community AGH by mean and IMCRA regions.

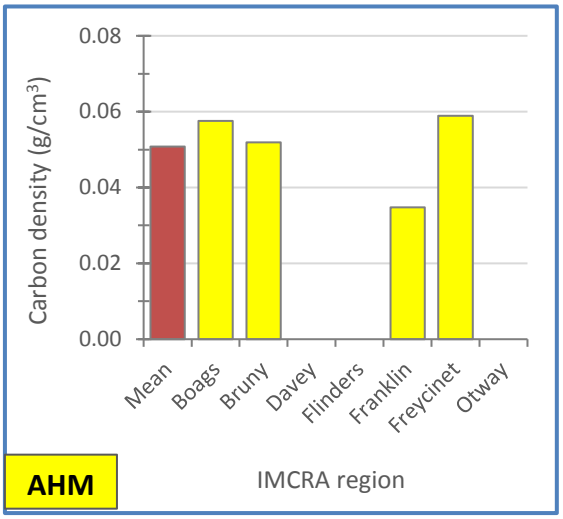

Figure 5.21: Carbon density of vegetation community AHM by mean and IMCRA regions.

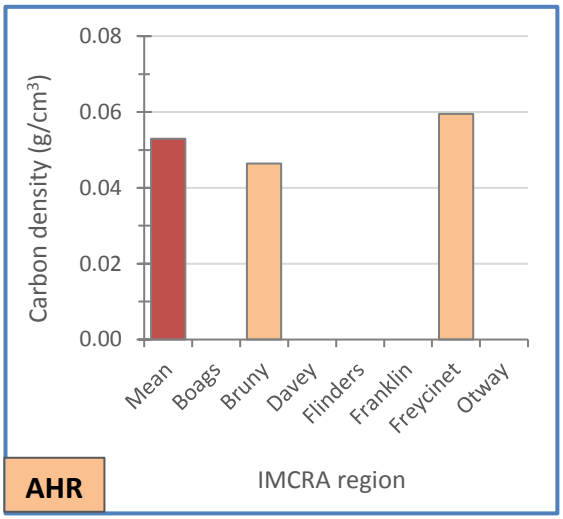

Figure 5.22: Carbon density of vegetation community AHR by mean and IMCRA regions.

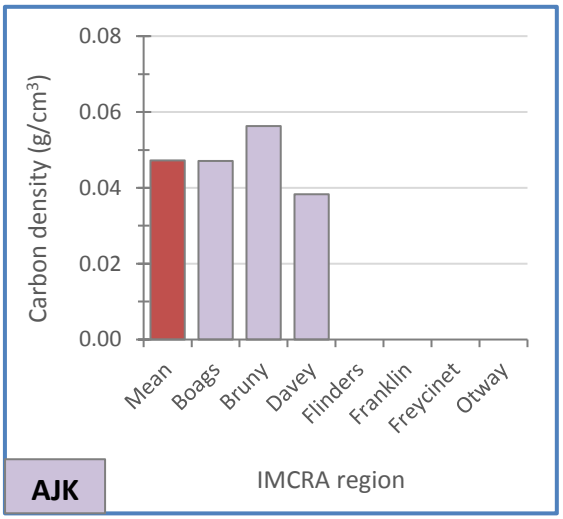

Figure 5.23: Carbon density of vegetation community AJK by mean and IMCRA regions.

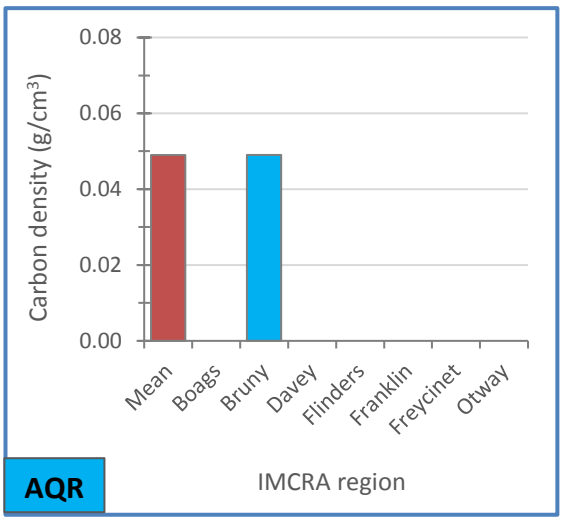

Figure 5.24: Carbon density of vegetation community AQR by mean and IMCRA regions.

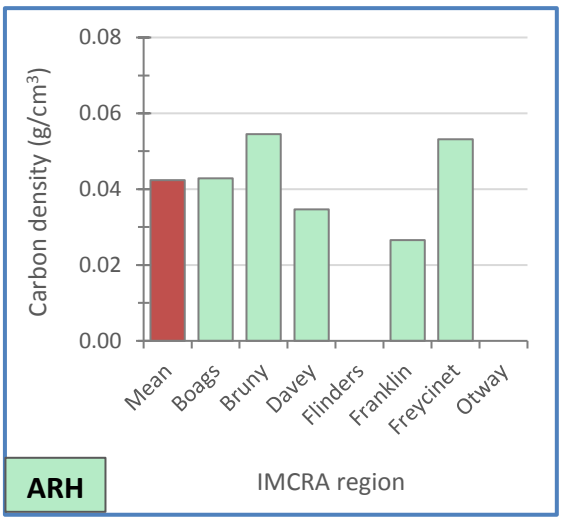

Figure 5.25: Carbon density of vegetation community ARH by mean and IMCRA regions.

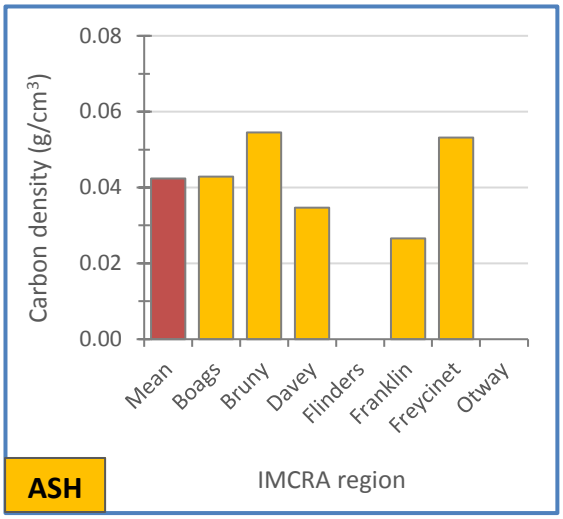

Figure 5.26: Carbon density of vegetation community ASH by mean and IMCRA regions.

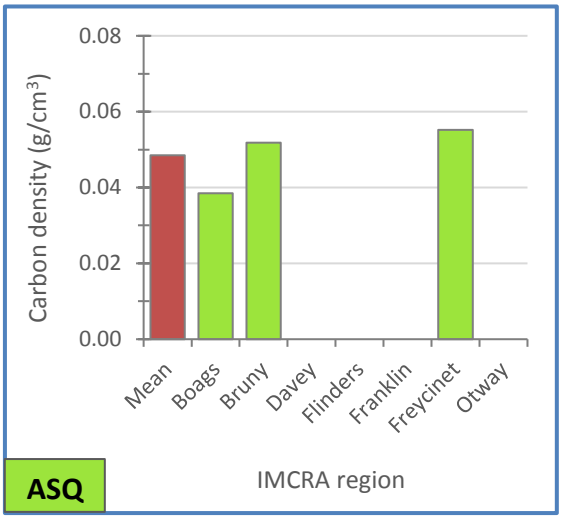

Figure 5.27: Carbon density of vegetation community ASQ by mean and IMCRA regions.

Vegetation community AGH (Figure 5.20) has highest carbon density in Bruny, while it has the lowest in Franklin. Community AHM (Figure 5.21) exhibits highest carbon density values in Boags and Freycinet, with lowest density value in Franklin, while community AJK (Figure 5.23) is highest in Bruny, with the lowest in Davey. Vegetation community ARH (Figure 5.25) has similar carbon densities in Bruny and Freycinet, while the lowest carbon density exists in Franklin. Community ASH (Figure 5.26) has greatest carbon density in Bruny and Freycinet, with the lowest value in Franklin, while ASQ (Figure 5.27) has highest carbon densities in Freycinet and Bruny, with lowest value in Boags.

IMCRA region by vegetation community

Soil carbon densities of individual IMCRA regions by mean and vegetation community are presented in Figures 5.28 to 5.32. Communities that are represented by less than five plots within each IMCRA region are not included. Regions Otway and Flinders have not been charted as no vegetation community was represented by five or more plots. Carbon densities are charted to g/cm^3 with all charts scaled to similar range to aid comparisons.

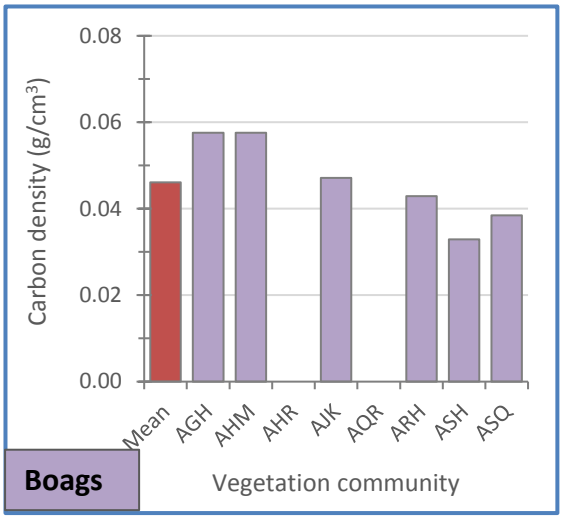

Figure 5.28: SCD of IMCRA region Boags by mean and vegetation community.

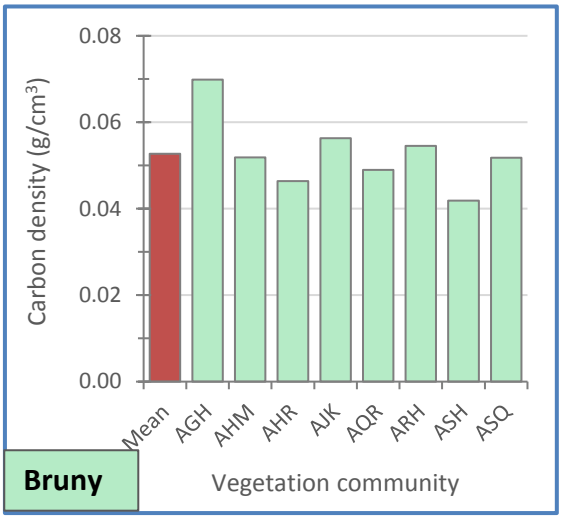

Figure 5.29: SCD of IMCRA region Bruny by mean and vegetation community.

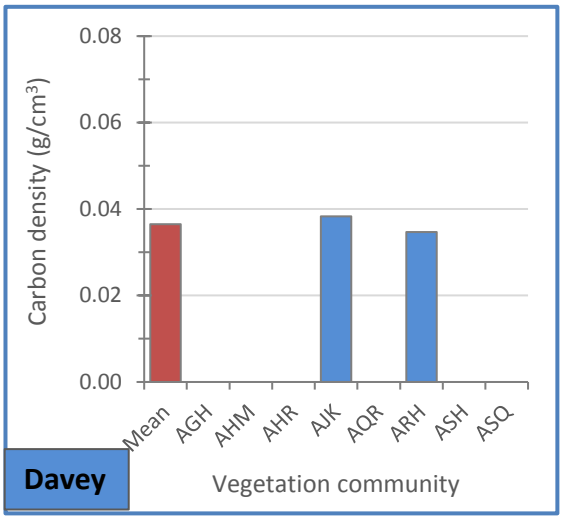

Figure 5.30: SCD of IMCRA region Davey by mean and vegetation community.

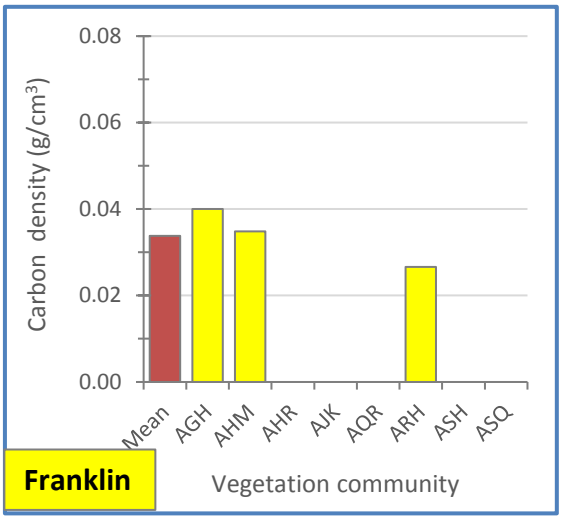

Figure 5.31: SCD of IMCRA region Franklin by mean and vegetation community.

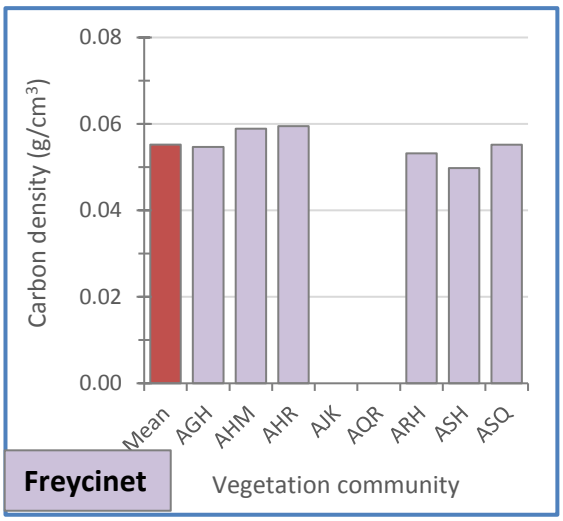

Figure 5.32: SCD of IMCRA region Freycinet by mean and vegetation community.

Regions **Otway** and **Flinders** have not been charted as no vegetation community was represented by five or more plots.

High values of carbon density are displayed in all vegetation communities in Bruny (Figure 5.29) and most communities of Freycinet (5.32), this contrasted by Davey (5.30) and Franklin (5.31). This is possibly due to a warmer, drier climate in the Bruny and Freycinet regions driving productivity as opposed to the colder, wetter climate in the other two regions. It is noted that data from Davey and Franklin is limited due to few sites and plots.

Carbon stocks

IMCRA region vegetation community

Carbon stocks of individual IMCRA regions by mean and vegetation community are presented in Figures 5.33 to 5.37. Communities that are represented by less than five plots within each IMCRA region are not included. Regions Otway and Flinders have not been charted as no vegetation community was represented by five or more plots. Carbon stock values have been calculated to mean depth of individual vegetation communities as Mg per ha at mean depth, thus a volumetrically based on one hectare. All charts are scaled to similar range to aid comparisons.

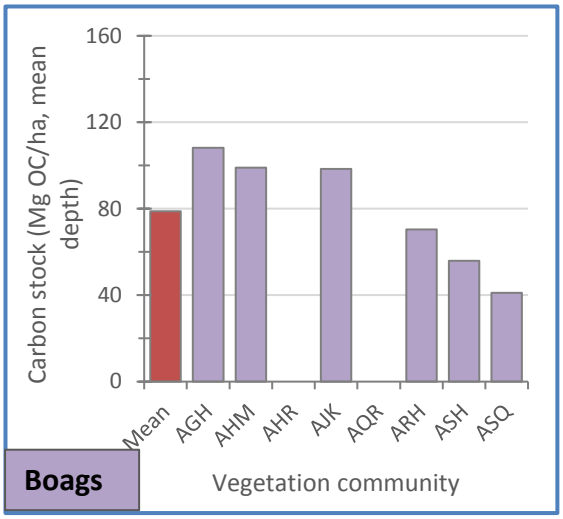

Figure 5.33: Carbon stock of IMCRA region Boags by mean and vegetation community.

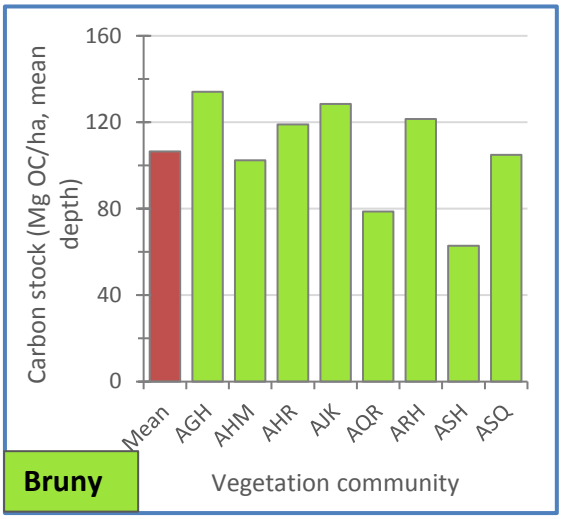

Figure 5.34: Carbon stock of IMCRA region Bruny by mean and vegetation community.

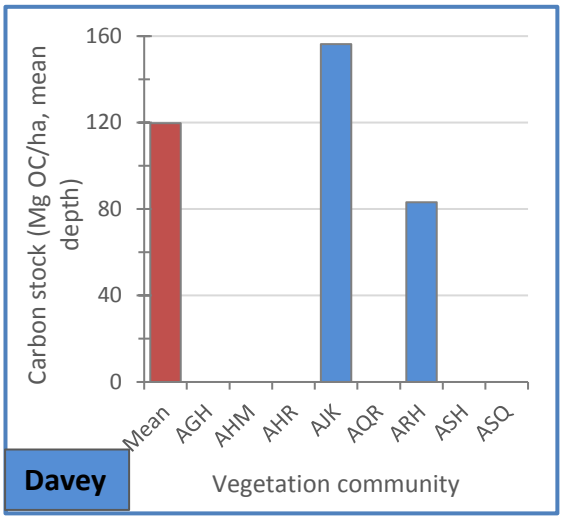

Figure 5.35: Carbon stock of IMCRA region Davey by mean and vegetation community.

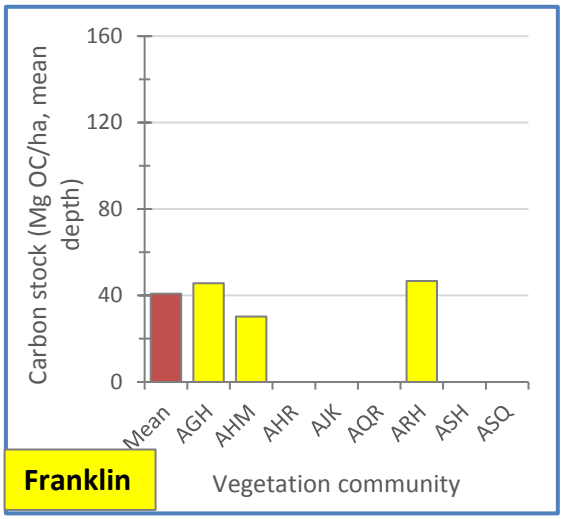

Figure 5.36: Carbon stock of IMCRA region Franklin by mean and vegetation community.

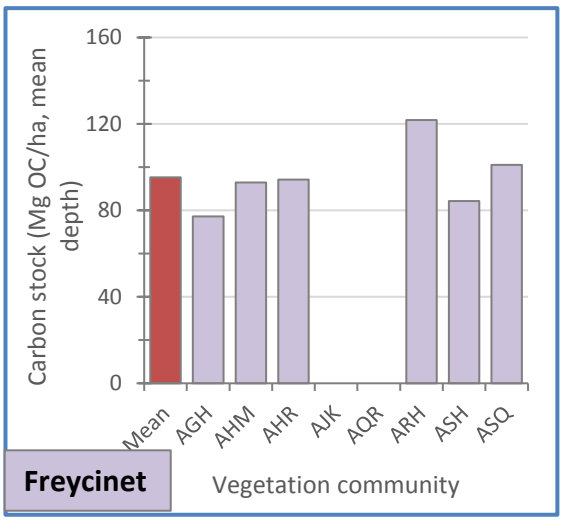

Figure 5.37: Carbon stock of IMCRA region Freycinet by mean and vegetation community.

Regions **Otway** and **Flinders** have not been charted as no vegetation community was represented by five or more plots.

Although some charts lack data, for example, Davey (5.35) and Franklin (5.36), there are some interesting comparisons. Most vegetation communities in Bruny (5.34) exhibit high levels of stored carbon, while those in Franklin are very low. All communities in Franklin have a lower carbon density than those equivalent communities in Bruny, however, this may be due to the low number of plots in all communities assessed in Franklin. Of particular note is vegetation community AJK in Davey, displaying a very high level of stored carbon, possibly due to greater soil depth in this community.

IMCRA regions

Estimated carbon stocks varied more than three-fold among the IMCRA regions (Figure 5.38). All plots are included to provide an information viewpoint. Although each region is not represented by an equal number of plots, the data has been displayed volumetrically as Mg OC per hectare by mean depth, thus presenting an indication of region by region carbon stocks.

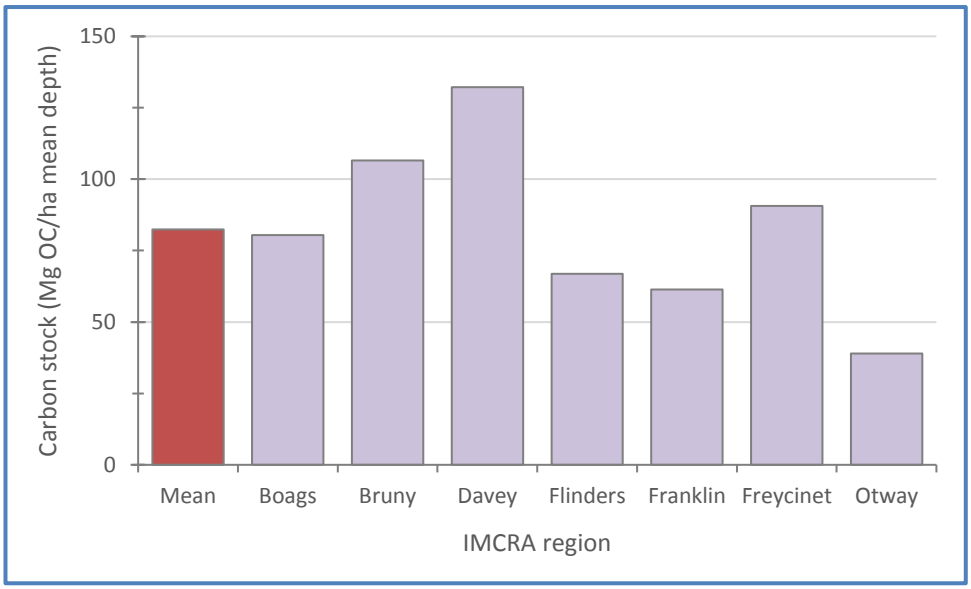

Figure 5.38: Carbon stock of mean and individual IMCRA regions. Stock values are volumetric as Mg OC per hectare by mean depth.

Davey exhibits the highest level of stored carbon by hectare, followed by Bruny, while Otway returned the lowest levels. Although the regions richest in coastal saltmarsh are Bruny and Freycinet (also the most studied regions), it is noteworthy that Davey tops the carbon store region, as, besides Franklin, it is the most depauperate region for coastal saltmarshes. Obviously, the high carbon store reflects the depth of the organic layer and the vegetation communities, principally composed of rushes (*J. kraussii*) in

Davey. However, this comes with a caveat as only four sites/17 plots were surveyed, due to the remoteness and limited accessibility of the region. The low carbon stock value for Otway may reflect the limited sites (n = 2) and plots (n = 14) surveyed, as well as the type of vegetation present. Here, the principal vegetation communities are AGH, AQR and ASH, all displaying lower carbon density values than the mean.

It is difficult to determine if carbon stock can be a determinate of IMCRA regionalisation due to insufficient data, for example, low number of sites/plots in the regions of Davey, Flinders, Franklin and Otway. This is compounded by difficult accessibility to Davey and Franklin regions, and the low number of saltmarshes sites in these four regions. However, the results do point to real differences between IMCRA regions, particularly in respect to carbon density and organic layer depth with vegetation community type playing a complementary role. This is evident in Davey and Franklin regions as the principle vegetation communities are dominated by rushes, communities generally high in carbon density and with deeper soils. To better determine if carbon stocks reflect IMCRA regionalisation, further study sites should be surveyed in regions that are presently under-represented in the dataset.

Issues encountered

There were a number of issues encountered when reviewing previous studies on carbon calculations and storage reported in the literature.

This study has shown that there is serious ambiguity in the literature when it comes to estimating carbon stock. If calculations are conducted using a "global" mean and applying this to other means, it has been demonstrated that overestimations can occur, in this case ~59%. This leads to a significant distortion of the true carbon store values in coastal saltmarshes. Many studies do not explicitly state how total carbons stocks are determined, though one did state that "total carbon stock was calculated using the mean C density from all cores" (Wollenberg *et al.* 2018, p. 7/14). The authors continue "C storage was also calculated individually for each core based on mean C density and depth of each core. As expected, due to the relatively constant C densities…sediment depth was a significant predictor of areal C storage and explained 96.9% of variation in new C storage". The most reliable method of carbon stock determination is by way of individual calculations using individual plot values of soil bulk density, depth, LOI

value converted to OC value using a conversion specifically generated for that purpose, for example, one "weighted" to vegetation cover/abundance and plot depth. This permits discretely generated values by plot which can be independently converted to carbon store per area to determine carbon store by area by vegetation class. Further refining factors can then be included, such as area (extent of saltmarsh), and depth of organic layer to determine total carbon stock.

In one study, a conversion formula was incorrectly applied to the LOI value of samples. The study reported the conversion from Craft *et al.* (1991) as $OC = 0.40(LOI) + (0.025 \times LOI)^2$. The correct conversion is slightly different $OC = 0.40(LOI) + 0.0025 \times LOI^2$, however this is enough to make a difference. Admittedly, low LOI values are barely affected, however, high LOI values are considerably underestimated. For example, with an LOI of 10%, use of the incorrect conversion results in an OC of 4.0625%, the correct result is 4.25%, this 4.41% higher. When a higher LOI value, such as 40%, is applied, the incorrect answer is 17%, the correct result should be 20%, this 15% higher. For comparisons in this study (detailed above), the Craft *et al.* (1991) conversion was applied to all plot LOI values. If the incorrect conversion was applied to the data from this study, the result would have seen an underestimation of 15% of the total carbon store in Tasmanian saltmarshes based on the Craft *et al.* (1991) conversion. It is clear that care must be taken when interpreting other work presented in the literature and transcribing conversions.

The units used for results can be confusing, especially in relation to carbon stores/stock. Literature cites g (grams), kg (kilograms), t (tonnes), Mg (megagrams, which by the way, equals one tonne), Tg (tetragrams), and Gg (gigagrams), these units applied to m^2 (square metres), m^3 (cubic metres), ha (hectares) or km^2 (square kilometres). Results appear as g/m^2, g/m^3, kg/m^2, Mg/ha, and just as Tg and Gg. Depth variations are haphazard, reported as 15cm, 20cm, 30cm, 50cm, 60cm, up to 96cm and 100cm. UK and Canadian studies seem to use g/m^3, European use kg/m^2, and Australian studies use Mg/ha, though one study (Qld) uses g/m^2. It was interesting to note that only one study used standard International System (SI) units (kilograms and metres), this from the EU (Belgium/Netherlands). Furthermore, validation around the mean is presented as SD (± standard deviation), SE (± standard error) or not stated. It appears that the methodology of applying units and presenting results is

arbitrary, the author selects which to use. One then speculates to the validity of carbon stock values, particularly expressed volumetrically (per hectare, ##m depth). This makes comparisons between studies extremely difficult and on dissemination of results to the public, nonsensical. Values should be expressed in SI units as this is an international standard (kg/m^2 or m^3), though this could result extremely large numerical values. It may be more prudent to express carbon stock as tonnes per hectare to a set depth of 0.01metre (on an area basis), as this is an acceptable "standard" useful for comparisons and when presenting results for public scrutiny, thus "tonnes OC per ha, 0.01m depth". Total carbon stocks on a volumetric basis can be presented as "tonnes OC per ha, ##m mean depth". It is acknowledged that in some cases, depth is difficult to achieve, or for that matter properly analyse, but in many cases, carbon stocks have been reported to a nominal depth. Here in Tasmania, saltmarsh soils are shallow making it far easier to obtain soil material to the full organic layer depth, it is appreciated that for other sites it may be far more difficult.

5.5 Conclusions

LOI

Loss on ignition has been shown to be a reliable method of determining organic matter values in these soils. Validation of the furnace is important, particularly in terms of position in the oven, ashing time and sample size, all variables which can influence precision in the results. This study found that position in the oven had little impact on the precision of the results in respect to SE and CV. Selecting the appropriate ashing time is important, as too short a time will not guarantee full combustion of all organic matter, whereas too long a period is time consuming and costly. Care must be taken with sample size, as small samples lose weight faster than large. This study showed that sample weights should ideally be 2 to 3 grams. Ignition temperature is also an important consideration. Too low temperature often does not allow for full combustion of organic matter, whereas too high can begin to consume carbonate material, decreasing the weight of the remaining material and inflating the LOI values. In conclusion, furnace validity is important, tests should always be conducted using standards of known LOI values, sample weights be restricted to a small range, and to consume organic material completely, ignition temperature maintained at approximately 550^{o}C for 3 hours.

Dry combustion

Dry combustion is a very reliable method in determining the total carbon content of soil samples. However, it is a financially costly method. At the onset, samples should be tested using a "fizz" or "champagne" method to determine whether carbonate material is present. If no fizzing/bubbling is present, no further treatment is required, and the total carbon content determined by dry combustion can be regarded as organic carbon. If samples do react to the fizz test, prior to dry combustion they should be treated with an acid solution that destroys any carbonates present and thoroughly rinsed with deionised water to remove any traces of the acid solution. Due to the high costs of dry combustion, it is recommended that at least 20% of the samples be determined for carbon content, with the samples selected on a randomised basis.

LOI to organic carbon conversions

This study has shown that it is imperative that localised conversion formulae (individual site, collection of sites, or in the case of this study, state-wide) be determined rather than using a universal conversion "as carbon content of soils is too variable for a single conversion factor, universally applied and based on questionable assumptions, to provide sufficiently reliable accuracy for reporting the quantity of carbon" (Pribyl 2010, p. 81). Conversion formulae from a known LOI value to organic carbon can be determined from a small range (~20-25% of the total number of samples). It is imperative that the conversion is generated from a full range of LOI values, that is, dry combustion samples should be chosen from the full range (minimum to maximum) rather than selected from a more restricted range. Once generated, the conversion can be applied to all the LOI values, including those used in its generation (as this can confirm the conversion's validity), and the carbon content of each sample determined. However, care must still be taken as factors such as depth of organic matter, decomposition rates, composition of organic matter and vegetation cover can lead to bias in the results (Pribyl 2010). To improve robustness of the results, LOI conversion formulae were determined for each of the eight vegetation communities and then were aligned to plots depending on individual vegetation community alliance. All conversion formulae, whether generic or specific to vegetation community, can be applied to Tasmanian coastal saltmarsh soils. However, it would be prudent to continue a process of dry combustion of samples and updating and improving the conversion formulae.

The conversions could be applied to soils more widely from SE Australia, however this should be done with care.

Carbon stocks

Evaluations of carbon stock in the past have been limited by uncertainties in published estimates. This work has shown the importance of improved precision in carbon estimates through focusing at vegetation community level and deriving more appropriate formulae. Tasmanian coastal saltmarsh carbon stocks rank mid-range when compared to other Australian jurisdictions. However, in relation to the two best studied States, NSW and Vic, (low sampling intensity precludes the remaining jurisdictions) Tasmanian carbon stocks are significantly lower. This is perhaps due to the shallow soils typical of Tasmanian saltmarshes (mean soil depth less than 30cm), whereas one metre depths are applied to carbon estimates from NSW and Vic. Nevertheless, it is not clear which method has been used when calculating carbon stocks, as this study has shown that when a global mean is used, large overestimations of carbon stocks can result.

Questions and study aims

The questions have been successfully addressed. Yes, there is a relationship between LOI550 and carbon, and yes, a suitable robust conversion from LOI to carbon can be developed. There are differences in carbon stock levels between vegetation communities, however, these differences are not significant. Carbon stock values for similar vegetation communities are dissimilar in different IMCRA regions, suggesting that position in the landscape does play a role in sequestered carbon.

Study aims: a) the establishment of robust generic and individual vegetation community conversions from LOI to organic carbon, and b) provision of a reliable carbon stock value have been met. The conversions can be applied to future Tasmanian coastal saltmarsh soil studies and the carbon store value will add to and update existing Australian estimates of carbon sequestered in coastal marshes. Finally, a reliable carbon stock value has been realised.

5.6 Acknowledgements

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5.8 Appendices

5A.1 Furnace test results – position in the oven

5A.2 Furnace test results – ashing time

5A.3 Sample weights

5A.1 Position in the oven

The standard placement of numbered crucibles in the oven is outlined in Figure 5A1.1

Rear of furnace/crucible number

19	20	21	22	23	24
13	14	15	16	17	18
7	8	9	10	11	12
1	2	3	4	5	6
43	44	45	46	47	48
37	38	39	40	41	42
31	32	33	34	35	36
25	26	27	28	29	30

Figure 5A.1.1: Sequence of the placement of numbered crucibles in oven

Standard 1

Table 5A.1.1: Standard 1 data and results.

							Mean	Median	Std Dev	CV
	51.20	50.78	50.61	50.89	51.05	51.30	50.97	50.97	0.261	**0.51%**
	50.78	50.73	51.11	50.55	51.97	51.09	51.04	50.93	0.505	**0.99%**
	50.37	50.21	50.31	50.54	50.39	50.58	50.40	50.38	0.140	**0.28%**
	49.99	51.07	50.78	50.54	50.31	50.58	50.54	50.56	0.373	**0.74%**
	50.57	50.91	50.22	50.66	51.30	50.75	50.73	50.70	0.361	**0.71%**
	50.37	50.46	50.10	50.41	50.42	51.02	50.46	50.41	0.300	**0.60%**
	49.75	49.71	49.67	50.52	50.08	50.11	49.97	49.92	0.327	**0.66%**
	50.61	49.60	49.76	49.91	50.80	49.98	50.11	49.95	0.480	**0.96%**
Mean	50.45	50.43	50.32	50.50	50.79	50.67	**50.53**			
Median	50.47	50.60	50.27	50.54	50.61	50.66		**50.55**		
Std Dev	0.450	0.547	0.495	0.277	0.626	0.464			**0.132**	
CV	**0.89%**	**1.08%**	**0.98%**	**0.55%**	**1.24%**	**0.92%**				**0.79%**

Mean - overall	50.53	**Mean - col**	50.53	**Mean - row**	50.53
Std dev - overall	0.49	**Std dev - col**	0.173	**Std dev - row**	0.378
CV - overall	0.97%	**CV - col**	0.94%	**CV - row**	0.68%
Std Err - overall	0.070	**Std Err - col**	0.070	**Std Err - row**	0.134

Standard 2

Table 5A.1.2: Standard 2 data and results.

							Mean	Median	Std Dev	CV
	37.21	37.36	37.50	37.97	37.81	37.64	37.58	37.57	0.282	**0.75%**
	37.20	37.35	37.26	37.39	37.87	37.75	37.47	37.37	0.275	**0.73%**
	37.20	37.38	37.14	37.00	37.27	36.98	37.16	37.17	0.153	**0.41%**
	37.65	37.43	37.30	37.19	36.91	37.18	37.28	37.24	0.248	**0.66%**
	37.74	37.59	37.86	38.02	37.92	38.04	37.86	37.89	0.172	**0.45%**
	37.05	37.04	37.04	37.30	37.91	37.97	37.39	37.18	0.442	**1.18%**
	36.85	37.83	37.60	37.01	38.05	37.56	37.48	37.58	0.467	**1.25%**
	37.35	37.71	37.56	37.70	37.23	37.44	37.50	37.50	0.195	**0.52%**
Mean	37.28	37.46	37.41	37.45	37.62	37.57	**37.46**			
Median	37.21	37.40	37.40	37.35	37.84	37.60		**37.40**		
Std Dev	0.294	0.248	0.272	0.405	0.420	0.364			**0.101**	
CV	**0.79%**	**0.66%**	**0.73%**	**1.08%**	**1.11%**	**0.97%**				**0.81%**

Mean - overall	37.46	**Mean - col**	37.46	**Mean - row**	37.46
Std dev - overall	0.34	**Std dev - col**	0.121	**Std dev - row**	0.210
CV - overall	0.91%	**CV - col**	0.89%	**CV - row**	0.75%
Std Err - overall	0.049	**Std Err - col**	0.04949	**Std Err - row**	0.074

Standard 3

Table 5A.1.3: Standard 3 data and results.

							Mean	Median	Std Dev	CV
	12.82	13.41	12.77	13.24	13.28	12.84	13.06	13.04	0.280	**2.15%**
	12.30	12.49	13.28	13.71	12.86	12.78	12.90	12.82	0.519	**4.02%**
	12.41	13.17	12.39	13.34	12.69	13.15	12.86	12.92	0.415	**3.23%**
	12.57	12.04	12.00	12.47	12.67	12.54	12.38	12.51	0.288	**2.32%**
	13.59	12.78	12.58	13.22	12.93	12.92	13.00	12.93	0.356	**2.74%**
	13.44	13.28	13.17	13.59	13.72	13.28	13.41	13.36	0.210	**1.57%**
	12.74	13.01	13.89	13.15	12.62	13.39	13.13	13.08	0.463	**3.53%**
	13.16	13.42	12.92	13.50	12.86	13.05	13.15	13.11	0.262	**1.99%**
Mean	12.88	12.95	12.88	13.28	12.95	12.99	**12.99**			
Median	12.78	13.09	12.85	13.29	12.86	12.99		**12.96**		
Std Dev	0.474	0.487	0.583	0.380	0.373	0.280			**0.111**	
CV	**3.71%**	**3.72%**	**4.54%**	**2.86%**	**2.90%**	**2.15%**				**2.96%**

Mean - overall	12.99	**Mean - col**	12.99	**Mean - row**	12.99
Std dev - overall	0.44	**Std dev - col**	0.149	**Std dev - row**	0.299
CV - overall	3.37%	**CV - col**	3.31%	**CV - row**	2.69%
Std Err - overall	0.063	**Std Err - col**	0.06087	**Std Err - row**	0.106

Standard 3 repeat

Table 5A.1.4: Standard 3 repeat data and results.

							Mean	Median	Std Dev	CV
	12.56	11.89	12.65	12.17	12.78	12.40	12.41	12.48	0.330	**2.66%**
	12.06	12.61	11.99	12.29	12.05	12.68	12.28	12.18	0.301	**2.45%**
	12.29	12.15	12.27	12.58	11.90	12.19	12.23	12.23	0.221	**1.81%**
	12.05	12.62	12.16	11.84	12.86	12.09	12.27	12.13	0.387	**3.15%**
	11.97	11.94	12.01	12.01	12.53	12.15	12.10	12.01	0.222	**1.83%**
	11.95	12.42	12.50	12.85	11.92	12.11	12.29	12.27	0.363	**2.95%**
	12.44	12.55	12.20	12.25	12.62	12.53	12.43	12.49	0.171	**1.37%**
	12.59	12.49	12.06	12.28	12.51	12.71	12.44	12.50	0.234	**1.88%**
Mean	12.24	12.33	12.23	12.28	12.40	12.36	**12.31**			
Median	12.18	12.46	12.18	12.27	12.52	12.30		**12.27**		
Std Dev	0.265	0.298	0.237	0.315	0.385	0.257			**0.066**	
CV	**2.18%**	**2.39%**	**1.94%**	**2.57%**	**3.07%**	**2.09%**				**2.31%**

Mean - overall	12.31	**Mean - col**	12.31	**Mean - row**	12.31
Std dev - overall	0.29	**Std dev - col**	0.067	**Std dev - row**	0.116
CV - overall	2.34%	**CV - col**	2.38%	**CV - row**	2.26%
Std Err - overall	0.041	**Std Err - col**	0.0273	**Std Err - row**	0.041

Standard 5

Table 5A.1.5: Standard 5 data and results.

							Mean	Median	Std Dev	CV
	10.76	9.96	10.28	10.88	10.72	10.63	10.54	10.67	0.350	**3.32%**
	10.12	11.29	10.11	10.48	10.51	10.37	10.48	10.43	0.431	**4.11%**
	10.14	10.31	10.45	9.78	10.14	9.91	10.12	10.14	0.246	**2.43%**
	9.98	9.80	9.99	9.65	10.47	9.83	9.95	9.91	0.283	**2.84%**
	11.50	11.08	11.39	10.57	11.23	10.81	11.10	11.16	0.352	**3.18%**
	11.45	10.71	10.85	11.28	11.03	10.95	11.05	10.99	0.276	**2.50%**
	10.52	10.86	10.90	10.84	11.01	10.08	10.70	10.85	0.344	**3.21%**
	11.22	10.85	10.78	10.93	10.49	11.50	10.96	10.89	0.355	**3.23%**
Mean	10.71	10.61	10.59	10.55	10.70	10.51	**10.61**			
Median	10.64	10.78	10.62	10.71	10.62	10.50		**10.66**		
Std Dev	0.617	0.531	0.470	0.571	0.366	0.575			**0.121**	
CV	**5.79%**	**4.93%**	**4.43%**	**5.33%**	**3.44%**	**5.47%**				**3.87%**

Mean - overall	10.61	**Mean - col**	10.61	**Mean - row**	10.61
Std dev - overall	0.50	**Std dev - col**	0.080	**Std dev - row**	0.423
CV - overall	4.75%	**CV - col**	4.90%	**CV - row**	3.10%
Std Err - overall	0.073	**Std Err - col**	0.03249	**Std Err - row**	0.149

5A2. Ashing time

Table 5A.2.1: Standard 2 – 2 hours – data and results.

							Mean	Median	Std Dev	CV
	37.02	36.98	37.03	37.39	37.26	37.51	37.20	37.14	0.223	**0.60%**
	37.77	37.48	37.61	37.28	37.70	36.93	37.46	37.54	0.315	**0.84%**
	37.69	37.70	37.32	37.42	37.36	37.55	37.51	37.49	0.165	**0.44%**
	37.42	37.63	37.04	37.36	37.59	37.54	37.43	37.48	0.217	**0.58%**
	36.99	37.45	37.63	37.60	37.06	37.95	37.45	37.52	0.365	**0.97%**
	37.16	37.34	37.21	37.16	37.14	37.40	37.23	37.18	0.109	**0.29%**
	37.64	37.59	36.97	36.64	37.44	37.18	37.24	37.31	0.390	**1.05%**
	37.59	37.26	37.27	37.67	37.57	36.88	37.37	37.42	0.298	**0.80%**
Mean	37.41	37.43	37.26	37.31	37.39	37.37	**37.36**			
Median	37.51	37.46	37.24	37.38	37.40	37.46		**37.44**		
Std Dev	0.314	0.232	0.255	0.319	0.227	0.357			**0.080**	
CV	**0.84%**	**0.62%**	**0.68%**	**0.85%**	**0.61%**	**0.95%**				**0.72%**

Mean - overall	37.36	**Mean - col**	37.36	**Mean - row**	37.36
Std dev - overall	0.28	**Std dev - col**	0.064	**Std dev - row**	0.120
CV - overall	0.75%	**CV - col**	0.76%	**CV - row**	0.70%
Std Err - overall	0.040	**Std Err - col**	0.02594	**Std Err - row**	0.042

Table 5A.2.2: Standard 2 – 4 hours – data and results.

							Mean	Median	Std Dev	CV
	37.80	37.22	38.24	37.77	37.95	37.64	37.77	37.78	0.340	**0.90%**
	38.23	37.90	37.91	38.10	37.46	37.10	37.78	37.90	0.425	**1.12%**
	37.74	38.35	38.13	37.86	37.65	37.81	37.92	37.83	0.265	**0.70%**
	37.20	38.27	38.69	37.94	37.87	37.83	37.97	37.90	0.496	**1.31%**
	39.16	39.12	39.33	38.64	38.98	38.89	39.02	39.05	0.240	**0.61%**
	38.51	38.58	38.15	38.23	38.70	38.43	38.43	38.47	0.208	**0.54%**
	38.70	37.98	38.24	38.31	38.22	38.06	38.25	38.23	0.251	**0.66%**
	38.37	38.42	38.55	37.80	38.10	38.53	38.29	38.39	0.290	**0.76%**
Mean	38.21	38.23	38.41	38.08	38.12	38.03	**38.18**			
Median	38.30	38.31	38.24	38.02	38.03	37.94		**38.13**		
Std Dev	0.617	0.555	0.447	0.301	0.510	0.568			**0.139**	
CV	**1.61%**	**1.45%**	**1.17%**	**0.79%**	**1.34%**	**1.50%**				**1.03%**

Mean - overall	38.18	**Mean - col**	38.18	**Mean - row**	38.18
Std dev - overall	0.50	**Std dev - col**	0.134	**Std dev - row**	0.418
CV - overall	1.30%	**CV - col**	1.31%	**CV - row**	0.82%
Std Err - overall	0.072	**Std Err - col**	0.05463	**Std Err - row**	0.148

Table 5A.2.3: Standard 2 – 5 hours – data and results.

							Mean	Median	Std Dev	CV
	37.88	38.24	38.36	38.25	38.19	37.89	38.13	38.21	0.201	**0.53%**
	38.18	38.44	38.14	37.95	37.84	39.02	38.26	38.16	0.424	**1.11%**
	37.70	38.00	37.77	38.21	38.43	38.35	38.08	38.11	0.303	**0.80%**
	38.40	37.69	37.87	37.30	37.50	38.06	37.80	37.78	0.397	**1.05%**
	39.24	37.64	38.38	38.52	39.21	39.05	38.67	38.78	0.621	**1.61%**
	38.93	38.57	38.65	38.54	38.66	38.87	38.71	38.66	0.158	**0.41%**
	38.15	38.74	38.98	38.92	39.09	38.34	38.70	38.83	0.378	**0.98%**
	38.80	38.23	38.30	38.46	39.03	38.68	38.58	38.57	0.309	**0.80%**
Mean	38.41	38.19	38.31	38.27	38.49	38.53	**38.37**			
Median	38.29	38.23	38.33	38.36	38.55	38.51		**38.34**		
Std Dev	0.536	0.398	0.394	0.486	0.620	0.439			**0.136**	
CV	**1.40%**	**1.04%**	**1.03%**	**1.27%**	**1.61%**	**1.14%**				**1.05%**

Mean - overall	38.37	**Mean - col**	38.37	**Mean - row**	38.37
Std dev - overall	0.47	**Std dev - col**	0.132	**Std dev - row**	0.345
CV - overall	1.24%	**CV - col**	1.25%	**CV - row**	0.91%
Std Err - overall	0.069	**Std Err - col**	0.05408	**Std Err - row**	0.122

5A3 – Sample weights

Table 5A.3.1: Standard 2 data and results.

	Wt.	LOI%	Wt.	LOI%	Wt.	LOI%	Wt.	LOI%	Wt.	LOI%	Wt.	LOI%	Wt.	LOI%
	1.247	37.97	1.535	38.04	2.166	37.87	2.503	37.26	3.041	37.71	3.635	36.91	4.112	37.83
	1.285	37.56	1.552	37.91	2.270	37.43	2.536	37.18	3.073	37.74	3.928	37.38	4.327	37.05
	1.316	37.04	1.560	37.86	2.308	37.44	2.567	37.65	3.173	37.64				
	1.333	38.02	1.589	37.01	2.328	37.00	2.585	37.20	3.202	37.21				
	1.371	37.92	1.711	37.30	2.360	37.39	2.692	36.98	3.395	37.35				
			1.729	37.30	2.392	37.36	2.796	37.35	3.440	37.27				
			1.756	37.60	2.463	37.81	2.853	37.20	3.484	37.56				
			1.815	37.14	2.490	37.70	2.903	37.23						
			1.866	36.85	2.500	37.50	2.993	37.75						
			1.904	37.04										
			1.934	37.97										
			1.942	37.19										
			1.958	37.59										
			1.981	38.05										
Mean	Weight range = 1.0 to 1.5g	37.70	Weight range = 1.5 to 2.0g	37.49	Weight range = 2.0 to 2.5g	37.50	Weight range = 2.5 to 3.0g	37.31	Weight range = 3.0 to 3.5g	37.50	Weight range = 3.5 to 4.0g	37.15	Weight range = 4.0 to 4.5g	37.44
Median		37.92		37.45		37.44		37.23		37.56		37.15		37.44
Std Dev		0.41		0.42		0.26		0.24		0.22		0.33		0.56
CV		**1.09%**		**1.13%**		**0.71%**		**0.65%**		**0.58%**		**0.88%**		**1.49%**
Max		38.02		38.05		37.87		37.75		37.74		37.38		37.83
Min		37.04		36.85		37.00		36.98		37.21		36.91		37.05
Mean		37.70		37.49		37.50		37.31		37.50		37.15		37.44
Std dev		0.41		0.42		0.26		0.24		0.22		0.33		0.56
CV		1.09%		1.13%		0.71%		0.65%		0.58%		0.88%		1.49%
No. samples		5		14		9		9		7		2		2
Std err		0.18408		0.11274		0.08823		0.08067		0.08251		0.2306		0.3932

Chapter 6

Saltmarsh plant species tolerance to edaphic factors and climate variables

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Chapter 6: Plant species tolerance to edaphic factors and climate variables

6.1 Introduction

Coastal saltmarshes are an ideal environment in which to study the adaptability of plant species to various abiotic characteristics. Ecological distinctiveness makes identification of a saltmarsh by plant species straightforward and each saltmarsh geographical uniqueness means that individual marshes can be studied as isolated entities (Partridge & Wilson 1988) or as a whole.

Traditionally, saltmarshes have been classified to three zones – low, middle and upper – each reflecting different vegetation communities made up from key plant species determined by tidal inundation (Chapman 1974; Adam 1990). Generally, the low zone experiences regular inundation at least once a day, the middle zone would undergo inundation during high astronomical tides, and the upper zones would be subject to extreme storm surges and aeolian borne salt deposits (Long & Mason 1983). Furthermore, edaphic (soil) factors, principally salinity and moisture, have been considered as most important in the distribution of plant species (Chapman 1974; Álvarez-Rogel *et al.* 2000), both factors controlled by tidal inundation. In many cases, the elevation gradient is also considered as a major co-variate, since it is negatively related to salinity and moisture which generally decline in value with a rise in elevation.

Many studies have been undertaken into the impacts of salinity and/or moisture on zonation and plant species incidence (Vince & Snow 1984; Pennings & Callaway 1992; Huckle *et al.* 2000; Álvarez-Rogel *et al.* 2001; Silvestri *et al.* 2005). Similar studies involving pH alone or in conjunction with salinity have also been conducted (Wherry 1920; Adams 1963). Some work, though to a more limited degree, has also considered climate impacts (Deil 2000; Fariña *et al.* 2018), however, this more in respect of an increase/decrease of salinity due to fluctuations in rainfall. Most studies have investigated plant zonation in relation to edaphic factors on single marshes (Callaway *et al.* 1990; Hackney *et al.* 1996), with relatively few studies carried out concurrently over a multiple sites (Davis *et al.* 1996; Woerner & Hackney 1997).

With the exceptions of a study on three saltmarshes of the Sydney (NSW) district (Clarke & Hannon 1967, 1970), work on temperature and salinity impacts on the

germination of three saline plant species (Greenwood & MacFarlane 2006) and salinity effects on species interactions (Greenwood & MacFarlane 2009), few studies have explored the role of abiotic factors in saltmarshes of Australia and how this can be applied in restoration projects. However, recent work in Australia has increasingly focused on carbon content in organic matter of saltmarsh soils (Howe *et al.* 2009; Mcleod *et al.* 2011; Macreadie *et al.* 2013; Saintilan *et al.* 2013; Lovelock *et al.* 2014; Kelleway *et al.* 2016; Owers *et al.* 2016; Lewis *et al.* 2018).

Many halophile plants occur in coastal saltmarshes irrespective of the underlying geology or the geographical location of the marsh (Álvarez-Rogel *et al.* 2000). To clarify the more common edaphic factors associated with saltmarsh vegetation zonation, and further, individual plant species suitable for restoring degraded areas, it is important to consider a wider approach to this research and carry out studies on a number of locations in a simultaneous manner (Álvarez-Rogel *et al.* 2000). Furthermore, a number of the studies identified above, have a focus on saltmarsh plant communities, those dominated by key plant species with a combination of other species (Álvarez-Rogel *et al.* 2000; Angiolini *et al.* 2013; Landi & Angiolini 2015), rather than as individual species and key abiotic relationships. Some studies though, do focus on individual plant species and specific abiotic factors, for example, salinity (Partridge & Wilson 1989; Ungar 1998), however, much of this work has been the focus of revegetating arid, saline, inland areas with suitable cropping species (Khan *et al.* 2000; Khan *et al.* 2001; Kachout *et al.* 2009). No studies have been identified where a comprehensive range of abiotic characteristics, including edaphic and climatic, have been examined, let alone identified key characteristics which should be included in any research of individual saltmarsh plant species and associated abiotic characteristics.

Herein –

Training sites/plots = those study sites/plots assessed and from which the draft coastal saltmarsh vegetation community key was formulated (Chapter 3);

Test 1 sites/plots = those study sites/plots used to test the draft vegetation community key in the field;

Test 2 sites/plots = those study sites/plots used to test the proposed vegetation community key and develop the final key; and

Combined = combined data from Training, Test 1 and Test 2 sites/plots to one dataset for analysis.

6.1.1 Questions and study aims

This chapter aims to understand the tolerance range of individual coastal saltmarsh plant species in the abiotic environment of Tasmania and provide information on which plant species are useful in saltmarsh restoration once soil and weather data have been obtained for the proposed restoration site.

Questions

1. How tolerant are individual coastal saltmarsh plant species to variable edaphic factors?
2. What role do climatic variables play in determining the presence of individual plant species?

Study aims

- Examine the tolerance of individual coastal saltmarsh plant species to varying conditions of soil and climate
- Identify a short list of plant species suitable for restoring degraded sites; and
- Provide a "decision-making" tool that identifies the habitable zone of suitable plants based on recorded edaphic factors and climate variables.

6.2 Methods

Drawing on previous data collected from Chapter 3 (Classification of coastal saltmarsh vegetation of Tasmania) and Chapter 4 (Soils of Tasmanian coastal saltmarshes), statistical analysis determined the range of edaphic and climatic values associated with individual coastal saltmarsh plant species. To simplify the work and the associated expenditure, only those edaphic factors which can be obtained for a minimal cost have been included (e.g. total carbon is not included as this analysis comes at a high cost), whereas a comprehensive range of climate variables have been included as these data are available at no cost. Edaphic factors and climate variables (now jointly referred as "attributes") used in the analysis include:

- Edaphic factors: loss on ignition at 550 and 850^{o}C (hereafter LOI550 and

LOI850), organic layer depth, pH, EC (used as a proxy for salinity, the meter used to record EC/salinity measured EC, this converted to salinity within the meter), moisture by volume, and bulk density (laboratory methods and analysis of individual factors are detailed in Chapter 4, Sections 4.2.2 and 4.2.3); and

- Climatic variables: mean annual rainfall, highest and lowest annual rainfall recorded during the period (years of records), mean annual maximum and minimum temperatures, highest maximum and lowest minimum annual temperatures recorded during the period (years of records), and mean highest and lowest daily solar exposure (years of records for weather stations is not consistent, no distinction has been made for period of records, therefore all data, irrespective of timeframes, are referred to in this study as long-term data).

Methods for data management, statistical analysis and identifying suitable plant species for restoration are described below.

6.2.1 Data management

Soil and vegetation data from the Training sites dataset were combined with soil and vegetation data from the Test 1 and Test 2 sites datasets to form a Combined sites dataset. The combined sites data were then aligned with climate data sourced from the Bureau of Meteorology (BOM) weather stations closest and most relevant to each individual study site. As some weather stations only record rainfall and solar exposure, temperature data have had to be sourced from an alternative weather station closest and most relevant (in respect of altitude and position in the landscape) to the study site. Details of weather stations and data used are listed in Chapter 3, Appendix 3A.1. The attribute of solar exposure, "the total amount of solar energy falling on a horizontal surface" (BOM 2017) is considered an important climatic variable as it is a critical factor in photosynthesis and plant growth (Campbell *et al.* 2006) and may have a bearing of individual species presence (or absence) from certain study sites. The daily global solar exposure is the total solar energy for a day received an individual point on the earth's surface with typical values ranging from 1 to 35 MJ/m^2. Global exposure values are measured from midnight to midnight and are usually lowest during winter or very cloudy days and highest in clear sunny conditions during the summer (BOM 2017).

6.2.2 Plant species selection

The plant species list was reduced from a total of 52 species to 16 (30%) species as analysed in R (Table 6.1). The plant species selection is based on presence in the total number of plots (n = 407) and possessing the greatest species mean cover of all species in the Combined sites dataset.

Table 6.1: Plant species, number plots that species is present, percent of total plots (n = 407) and mean cover. Species list in number of plots present, then by mean cover per plot.

Plant species	No. plots present	% of total plots	Mean cover per plot (%)
Sarcocornia quinqueflora	288	70.8	48.4
Juncus kraussii	180	44.2	44.6
Samolus repens	147	36.1	23.1
Selliera radicans	92	22.6	25.0
Tecticornia arbuscula	62	15.2	44.7
Gahnia filum	56	13.8	35.4
Austrostipa stipoides	55	13.5	31.7
Suaeda australis	43	10.6	17.8
Hemichroa pentandra	41	10.1	32.2
Disphyma crassifolium	39	9.6	25.4
Apodasmia brownii	32	7.9	31.7
Sarcocornia blackiana	26	6.4	21.0
Poa labillardierei	16	3.9	26.3
Schoenoplectus pungens	10	2.5	30.3
Wilsonia backhousei	5	1.2	38.0
Zoysia macrantha	3	0.7	38.3

Either individually, or in combination, 12 of the selected plant species were representative of all vegetation communities that are found in Tasmanian coastal saltmarshes, the remaining four species displayed high presence and species mean values particularly in study sites surveyed in the Test 1 and Test 2. Two species, *Hemichroa pentandra* and *Selliera radicans* were evident in the Training sites vegetation survey, however in a lower number of plots with a low species mean. The presence of the two species increased in the Test 1 sites, seemingly more evident in study sites on Tasmania's northern and east coasts, areas more intensely surveyed during this round of assessments. A third species, *Schoenoplectus pungens,* was recorded in Test 2 sites, those found on Tasmania's west coast. The high mean cover of *S. pungens* is due to its spreading form hence its inclusion.

Four species, *Poa labillardierei, S. pungens, Wilsonia backhousei* and *Zoysia macrantha,* though

exhibiting moderately high cover due to their spreading forms, were removed from the list as presence was exceedingly low (<4% of total plots), therefore deemed to be unrepresentative of total plots.

6.2.3 Plant species abbreviations

A list of abbreviations to plant species (including common names) displayed in figures and tables in the following sections is presented in Table 6.2.

Table 6.2: Abbreviations for plant species in the following figures, common names from Prahalad (2014). Plant species identified to vegetation communities (as defined in Chapter 3). Note: some species are found in more than one vegetation community. Species and vegetation communities order is alphabetical.

Species Identifier	Species name	Common name	Vegetation community's presence (refer to Chapter 3)
Apo_bro	*Apodasmia brownii*	Course twine-rush	AHR, AJK, ARH
Aus_sti	*Austrostipa stipoides*	Coast spear-grass	AGH
Dis_cra	*Disphyma crassifolium*	Round-leaf pigface	AGH, AHM, ASH
Gah_fil	*Gahnia filum*	Chaffy saw-sedge	AGH
Hem_pen	*Hemichroa pentandra*	Trailing saltstar	AHM, AHR, AQR, ASH
Jun_kra	*Juncus kraussii*	Sea rush	AHR, AJK, ARH
Sam_rep	*Samolus repens*	Creeping brookweed	AHM, AHR, AQR, ARH, ASH
Sar_bla	*Sarcocornia blackiana*	Thickhead glasswort	AGH, AHM, ASH,
Sar_qui	*Sarcocornia quinqueflora*	Beaded glasswort	AGH, AHM, AQR, ARH, ASH, ASQ
Sel_rad	*Selliera radicans*	Shiny swampmat	AHM, AHR, AQR, ARH, ASH
Sua_aus	*Suaeda australis*	Austral seablite	AGH, AHR, AQR, ARH, ASH
Tec_arb	*Tecticornia arbuscula*	Shrubby glasswort	ASH

6.3 Statistical analysis

Using MS Excel, charts were prepared where individual plant species were fitted against separate characteristics to provide a visual representation of plant species ranges to those characteristics, either soil or climate.

6.3.1 Boxplots

Boxplots are an excellent method of graphically displaying the variations between plant species by examining different edaphic factors. In R, boxplots were created to display the distribution of each plant species across individual variables to show the minimum, 1st quartile, median, 3rd quartile and maximum of the data. This enabled a clear appreciation of "best range" or "fit" for individual plant species and identified any outliers which are outside the interquartile range. As outliers can give a misleading

interpretation of the range a species is present (within each characteristic), the interquartile range demonstrates the ideal conditions of that characteristic in which the plant species is present. Boxplots are presented for the 12 plant species across both edaphic factors and climate variables.

6.3.2 Plant species, edaphic and climate attributes (ANOVA)

ANOVA was used to compare the means of plant species by individual attributes and Tukey post hoc tests used to test for significant differences between species means, and further tested to identify species that differ significantly from other species.

6.3.3 Plant species similarities/dissimilarities

An output from a Tukey post hoc test provides alphabetical annotations that represent similarity/dissimilarity between each plant species. A comparison can be drawn for each edaphic factor and climate variable, and from this, either individual or groups of species that are significantly different to others for a particular factor or variable, can be identified.

6.3.4 Non-metric multidimensional scaling (nMDS) ordination

An nMDS is considered one of the better methods of ordination for ecological data (Clarke & Warwick 2001; Kent 2012) and is now widely used. Its purpose is to build an ecologically meaningful arrangement of the plots, which can then be overlain with attributes such as plant species, climate variables and soil factors. The output, which includes attribute axis coordinates, and the visual display, helps clarify the relationships between the communities.

The ordination is a plot-based 2D view of all plots incorporated in this study. It is generated on plant species cover abundance of all species found during assessment of Training, Test 1 and Test 2 sites. Separately, the 12 selected plant species were fitted on the ordination. To examine trends and relationships, the following process was implemented:

- The Combined dataset was reduced to the 12 identified plant species;
- The climate data was standardised as various variables had different scales, for example, temperature (0 to 20^{o}C) and rainfall (0 to 2500mm);

- The soil composition and bare ground data was transformed to mid-point values, then all the edaphic factors re-scaled as various factors had dissimilar scales, for example, pH (range 0 to 14) and moisture (0 to 100%);
- The plant species cover abundance classes (1 to 6) were transformed to midpoint percentage values (where 1 = 0.5%, 2 = 3.0%, 2 = 15.0%, 4 = 37.5%, 5 = 62.5% and 6 = 87.5%);
- Produce a plot-based ordination fitted with plant species, climate variables and edaphic factors at $p<0.005$; and
- Tabulate coordinate values for each set of features.

6.3.5 Plant species suitability

An individual diagram of each of the 12 plant species is presented, detailing the acceptable "habitable/ecological" range for the most important edaphic factors and climate variables, these species suitable as candidates for coastal saltmarsh restoration in Tasmania. Decision making tools for three selected key plant species and instructions in their use are introduced, these to be made available for use by the public.

6.4 Results and discussion

The following section incorporates a combination of both results and discussion, as several results require comment before progressing to subsequent results. Within the following text, rainfall is expressed as mm (millimetres), temperature as ^{o}C (degrees centigrade), solar exposure as MJ/m^2 (megajoules per square metre), organic layer depth as cm (centimetres), pH values are standard pH units, EC vales are expressed as dS/m (decisiemens per metre), bulk density as g/cm^3 (grams per cubic centimetre), while bare ground cover, moisture, LOI550, LOI850 and composition (peat, sand, loamy-soil) are all expressed as % (percentage). All means are reported to standard error. **Note:** The term range, which is used to describe the minimum and maximum values (the limits) of an observation (e.g. pH 6.56 to 7.26, or EC 14.3 to 21.4), and the term spread, used to describe the difference between the limits (the extent) of an observation (e.g. from above, 0.70 or 7.1) are presented as pH 6.56-7.26, 0.70, or EC 14.3-21.4, 7.1. Results have been comprehensively reported.

Note: all following tables and figures display plant species in an alphabetical sequence.

6.4.1 Plant species and edaphic factors

Descriptive Charts

Graphical display charts of plant species fitted against grouped edaphic factors: a) LOI550, LOI850, organic layer depth (Figures 6.1 to 6.3); b) pH, EC (Figures 6.4 to 6.5); and c) moisture by volume and soil bulk density, are presented in Figures 6.6 and 6.7.

The charts visually demonstrate the tolerance range of plant species to individual edaphic factors. Generally, *Juncus kraussii, Samolus repens, Sarcocornia quinqueflora* and *S. radicans* were found over the greatest range within many edaphic factors (e.g. LOI550, organic layer depth, moisture by volume). These species can be classed as "generalists", each demonstrating a greater amplitude to the physical environment. This may be a result of the high incidence of each species throughout all plots (288, 180, 147 and 92 plots respectively), however, field observations do support the notion of these species being "generalists". The range of salinity observed by several plant species found in local coastal saltmarshes has been examined outside Tasmania. These results can be compared to this study; however, comparisons must be considered with care as genotype variations can occur. The concept of specific saltmarsh plant species being generalist is supported by several findings, for example:

In North America, *Juncus roemerianus,* a saltmarsh reed found mainly in the southeast of the continent occupying a similar habitat to that of *J. kraussii,* inhabited a range of sites of varying salinity (0.5 to 38.0‰ = EC 1 to 57), pH (5.72 to 8.93) and organic matter content (0.5 to 50.7) (Christian *et al.* 1990; Woerner & Hackney 1997);

A study in the Otago region of South Island, New Zealand found that *Juncus maritimus* (now conspecific with *J. kraussii*) inhabited a salinity range of 4 to 32‰ (EC of 7.2 to 49), *S. repens* occupied a range of 5 to 24‰ (EC of 9 to 37.8), *S. quinqueflora* was found in a range of 8 to 35‰ (EC of 13.8 to 53), while *S. radicans* inhabited a salinity range of 0 to 15‰ (EC of 0 to 24.7) (Partridge & Wilson 1987); and

Clarke and Hannon (1969) found that the habitat of *J. kraussii* in three localities of the Sydney region (NSW, Australia) ranged in EC from 11.1 to 103.6, while *Arthrocnemum australasicum* (now identified as *S. quinqueflora*) tolerated salinity levels 10 to 35‰ (EC 17 to 53) in salinity trials (Clarke & Hannon 1970).

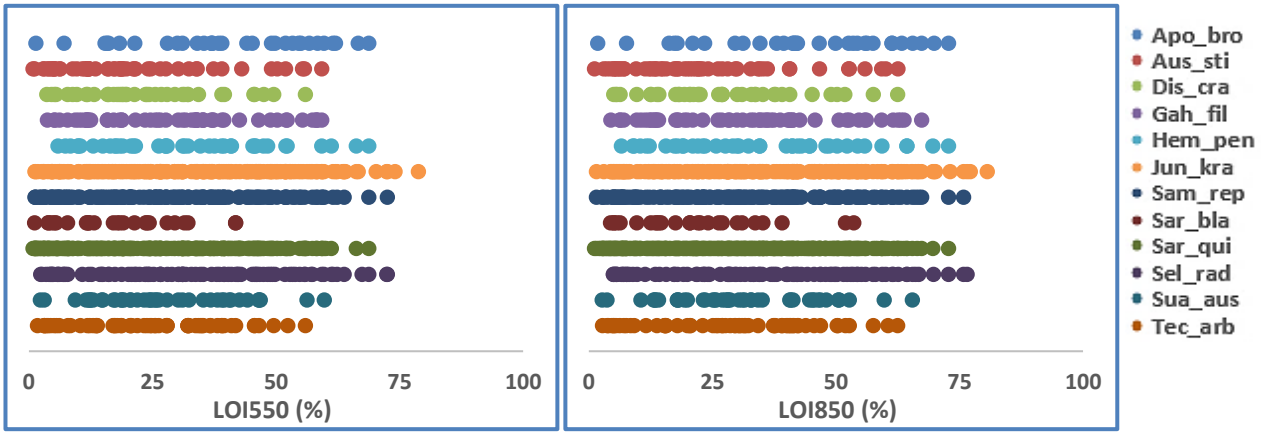

Figure 6.1: Plant species LOI550.

Figure 6.2: Plant species LOI850.

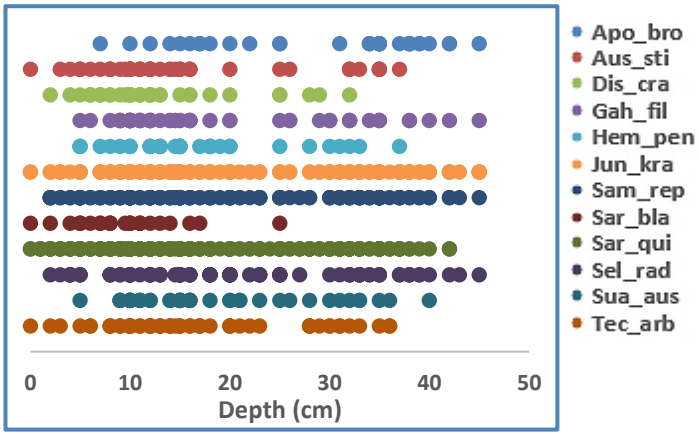

Figure 6.3: Plant species organic depth.

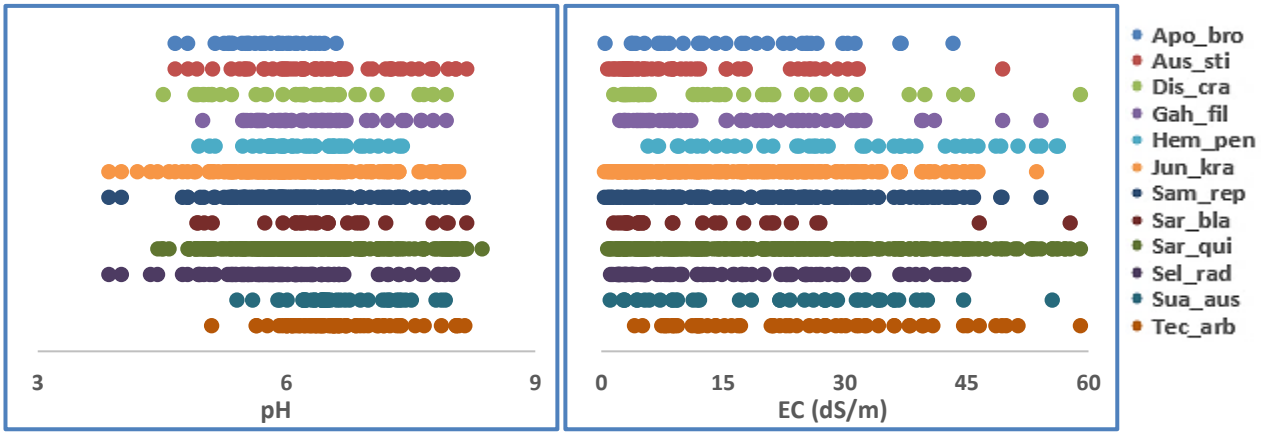

Figure 6.4: Plant species pH.

Figure 6.5: Plant species EC.

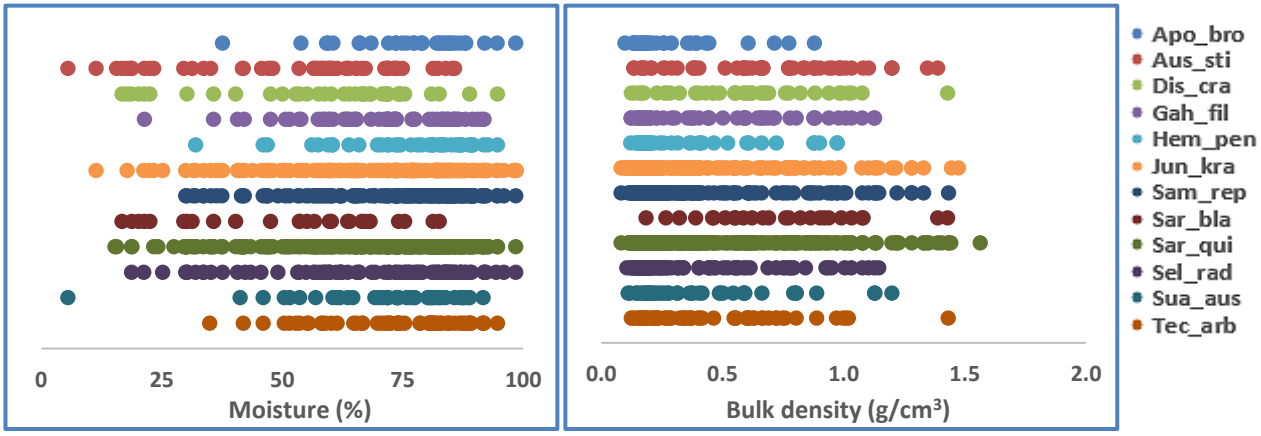

Figure 6.6: Plant species moisture by volume.

Figure 6.7: Plant species soil bulk density.

Conversely, species that display a "narrower" range, for example, *Sarcocornia blackiana* (LOI550, organic layer depth), *Austrostipa stipoides* (EC), *Apodasmia brownii* (pH, bulk density) and *Suaeda australis* (pH) could be a result of a more limited presence across sites (26, 55, 32 and 43 plots respectively). However, the graphical charts could be interpreted in another way – plant species that are found in a narrow range may only tolerate that limited range in each edaphic factor and could therefore be classified as "specialists". Again, this notion is supported by observations in the field. Some species, such as *H. pentandra* (LOI550, moisture by volume), *Gahnia filum* (pH, EC, moisture by volume) appear to tolerate a more "generalist" range, however, closer examination shows that some individual data points may be "outliers", points that lie outside the main body of data. Obviously, care must be taken when interpreting the above graphic displays, however, they do provide a good visual understanding of the range each individual plant species appears to tolerate in the field.

Following examination of all the graphical display charts, it becomes obvious that no single edaphic factor is a determinant of presence/absence of individual plant species, rather, it appears that a combination of two or more factors (e.g. pH and EC), may determine species presence and survivability.

Plant species and edaphic factors

ANOVA

Plant species edaphic factors ANOVA outputs of are presented in Table 6.3.

Table 6.3: ANOVA outputs of all assessed edaphic factors. The edaphic factor order is by graphical display charts (above) and grouped to relevance (those factors that have a semblance of commonality, although this could be disputed!).

Edaphic factor	Df	F value	p-value	
LOI550 (%)	11, 904	6.272	4.90e-10	***
LOI850 (%)	11, 904	5.434	2.02e-08	***
Organic layer depth (cm)	11, 904	9.187	9.76e-16	***
pH	11, 904	5.884	2.76e-09	***
EC (dS/m)	11, 904	9.185	9.85e-16	***
Moisture by volume (%)	11, 904	10.100	<2e-16	***
Soil bulk density (g/cm^3)	11, 904	7.073	1.36e-11	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

There was a significant difference between plant species ($p<0.001$) in each edaphic factor. The very low p-values indicated that at least one species within each factor was significantly different to all other plant species within that factor.

Boxplots

Boxplots of plant species fitted against key grouped edaphic factors: a) LOI550 and LOI850 and organic layer depth (Figures 6.8 to 6.10); b) pH and EC (Figures 6.11 and 6.12); and c) moisture by volume and soil bulk density, are presented in Figures 6.13 and 6.14.

The following figures display the distribution of each plant species across individual factors to show the minimum, 1st quartile, median, 3rd quartile and maximum of the data and conveys the "ecological/best fit" (interquartile) range of plant species to specific edaphic factors. Therefore, when viewing the boxplot (below) against the display chart (above), differences will be observed. For example, in edaphic factor EC, display chart Figure 6.5, *S. quinqueflora* exhibits a full range from 0 to 58, yet when viewed from the boxplot point of view, the same species appears to have a range from 9 to 34, this the interquartile range (25 to 75% of the data). This suggests that one or both charts are incorrect, however, each is showing the same data, simply presenting it in a different format.

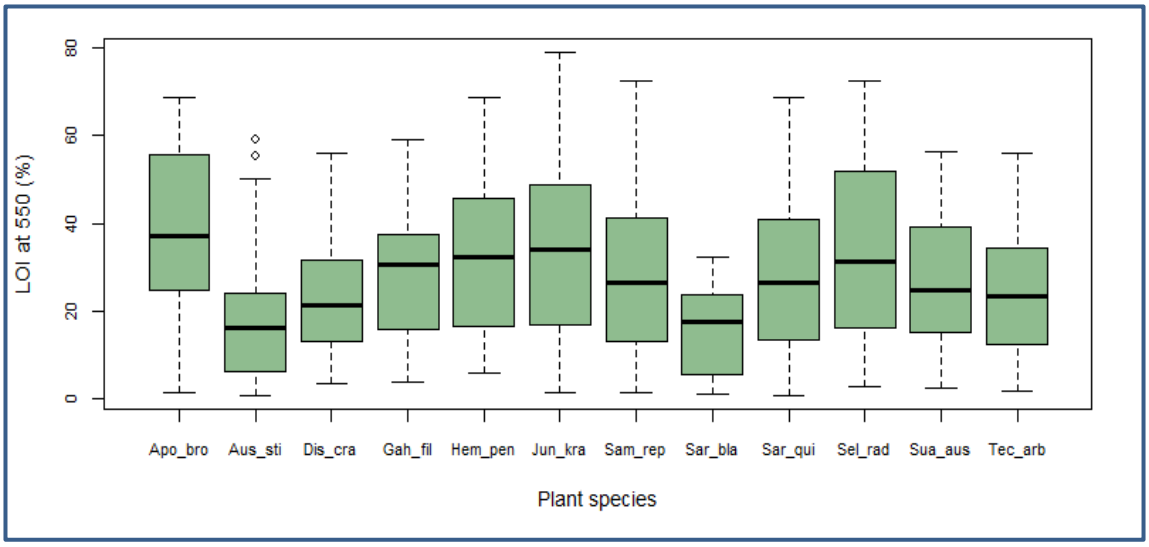

Figure 6.8: Boxplot of plant species and LOI550 (%).

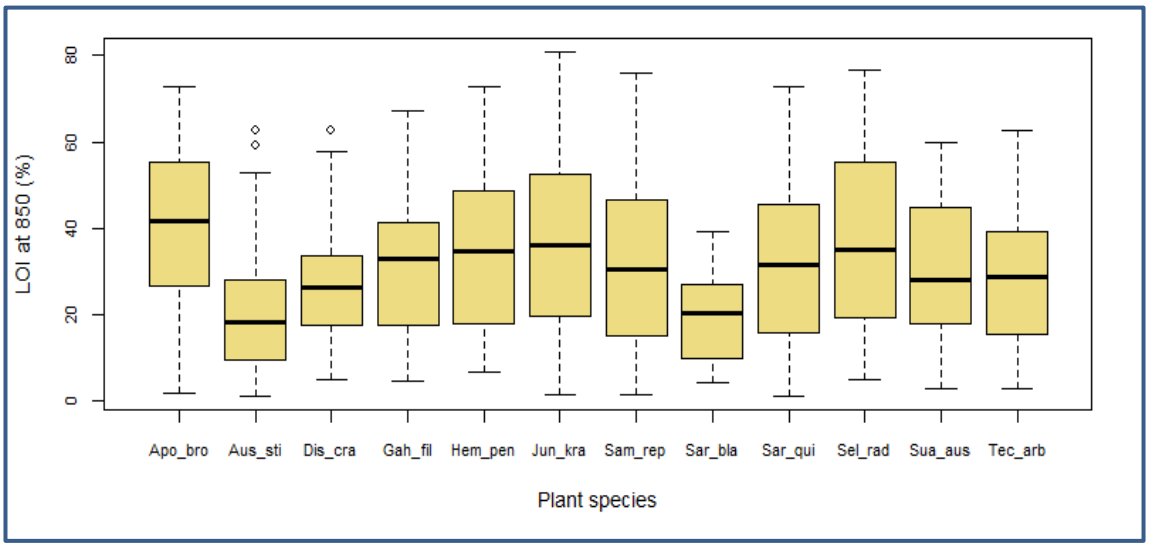

Figure 6.9: Boxplot of plant species and LOI850 (%).

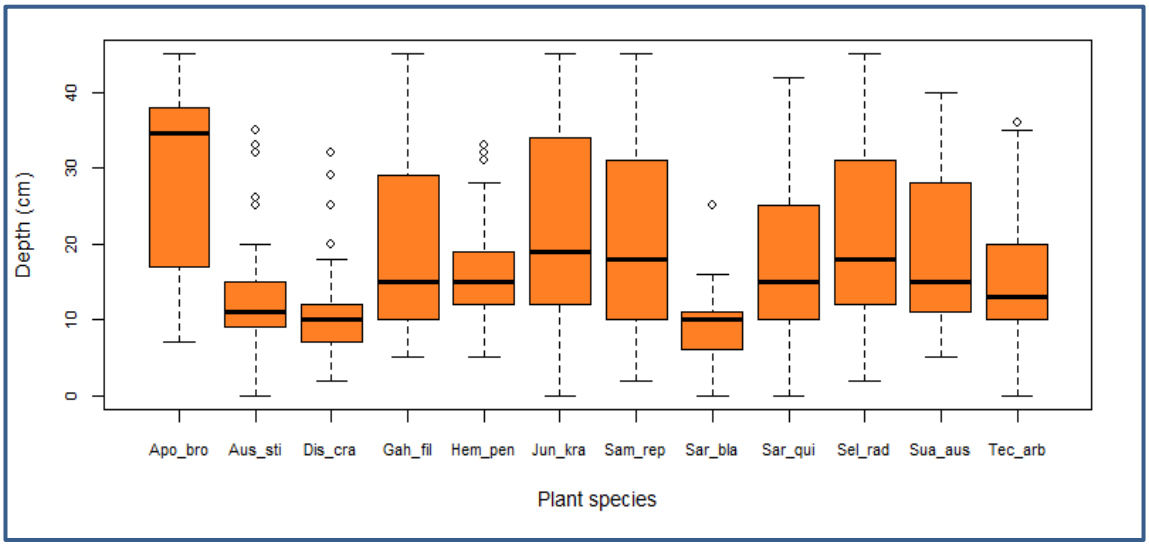

Figure 6.10: Boxplot of plant species and organic layer depth (cm).

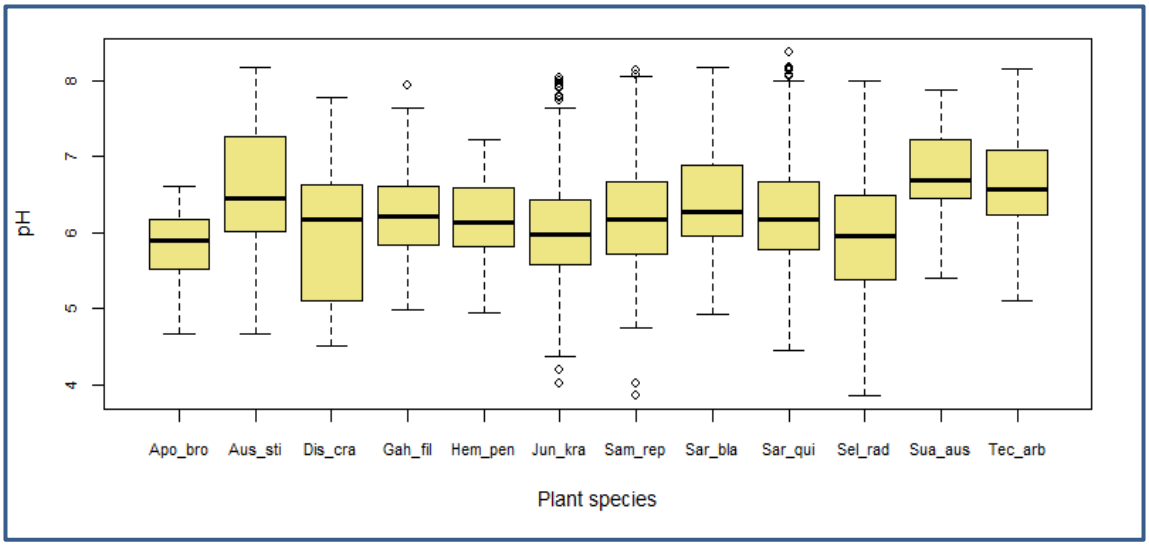

Figure 6.11: Boxplot of plant species and pH.

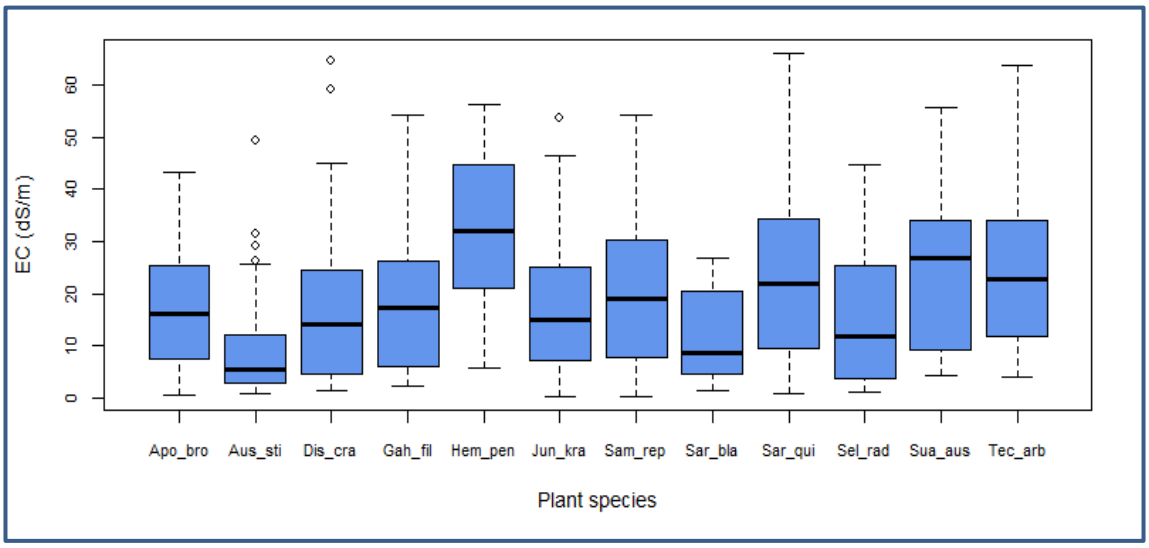

Figure 6.12: Boxplot of plant species and EC (dS/m).

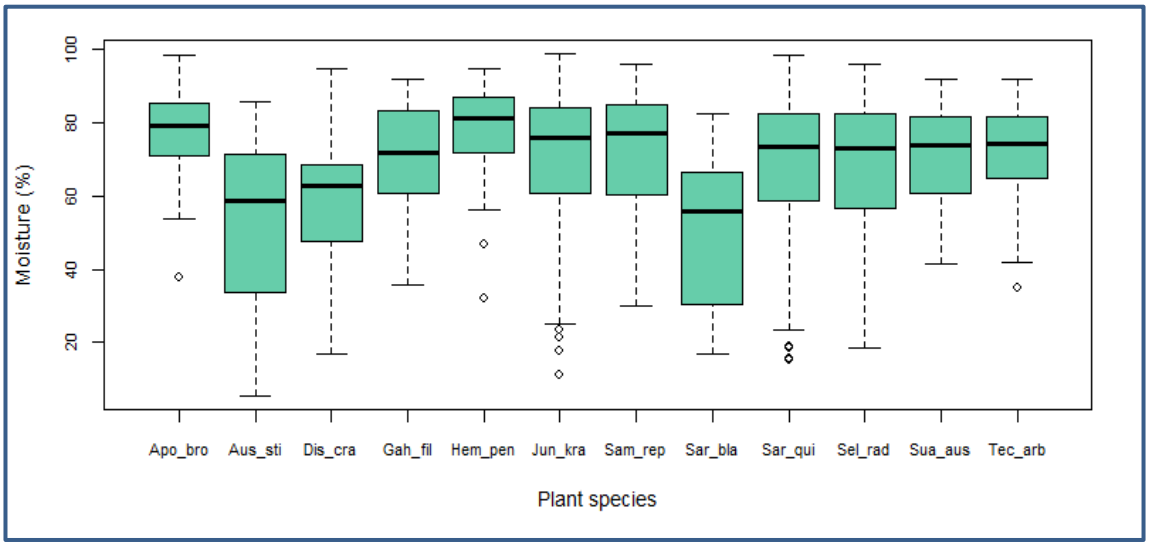

Figure 6.13: Boxplot of plant species and soil mositure by volume (%).

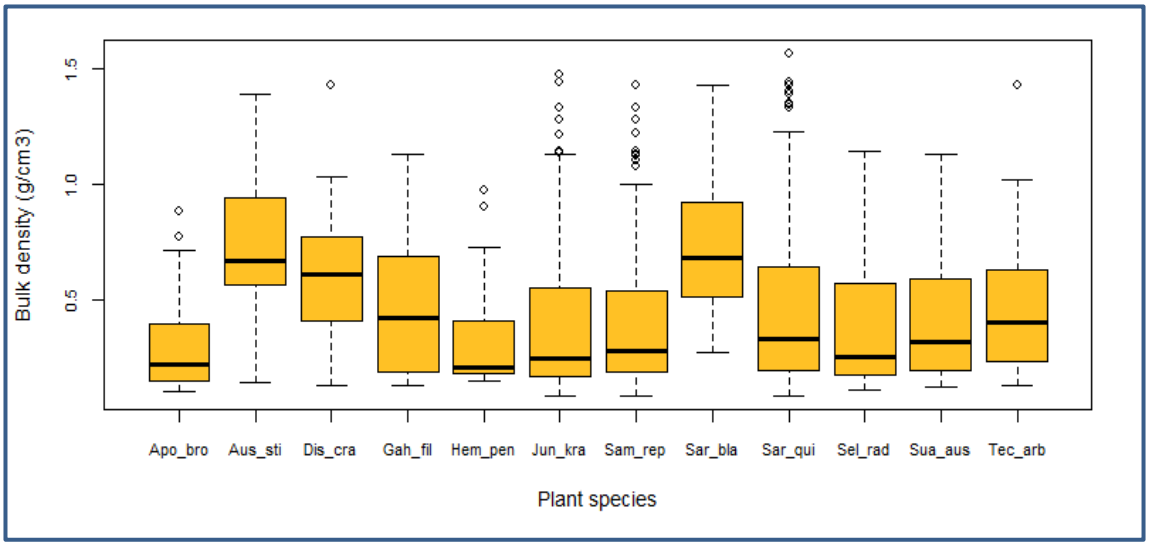

Figure 6.14: Boxplot of plant species and soil bulk density (g/cm^3).

Here, plant species that display a large (tall) box, have a greater ecological fit/tolerance across the range of each edaphic factor. Examples include, *J. kraussii* and *S. radicans* in LOI550 and organic layer depth (this would be anticipated as there is an expected positive relationship between LOI and organic depth); *Disphyma crassifolium* in pH; *H. pentandra*, *S. quinqueflora* and *S. australis* in EC; *A. stipoides* and *S. blackiana* in moisture by volume. Plant species that display a somewhat restricted range (have a smaller ecological fit/tolerance across a range) within an edaphic factor include, *D. crassifolium* and S. *blackiana* in LOI and organic layer depth; *A. brownii, G. filum* and *H. pentandra* in pH, and *A. stipoides* in EC, *A. brownii* and *H. pentandra* in moisture by volume and bulk density (a predictable outcome as there is a negative correlation between the two factors).

The boxplots, in a graphical sense, display which edaphic factors are important to study when considering species diversity throughout a saltmarsh. LOI500, LOI850 and pH indicate that most species display tolerance over a high range where many species ranges overlap. For example, *G. filum, H. pentandra* and *S. quinqueflora* have similar ranges as well as similar mid-points. This immediately suggests that possibly pH should be not considered a suitable factor when determining a relative value of individual factor significance. A contrasting situation occurs with EC, moisture and bulk density, where each display individual species occupying a specific range in which ranges of several plant species do not overlap. For example, the EC range of *A. stipoides* and *S. blackiana* end before that of *H. pentandra* begins, or in the case of bulk density where the range of

S. repens ends before that of *S. blackiana* begins. Here, it can be suggested that either independently or combined, the three factors can be considered one of the reasons for plant species presence (or absence) in saltmarshes. What is important to remember, is that of all the edaphic factors measured in this study, none appear to be the primary factor that leads to presence/absence of saltmarsh plant species, it is highly likely that a combination of two or more play a key role species establishment and ongoing survival.

By reviewing each boxplot in turn, selecting species that display the greatest ecological/tolerance range within each edaphic factor (Figures 6.8 to 6.14) and then overall from the display charts (Figures 6.1 to 6.7), we can identify species that would be suitable as "pioneer" plants suitable for saltmarsh revegetation or restoration. Reviewing the factors again, we can identify plants which will be suitable for "niche" habitats that in turn will improve plant species diversity within the restored saltmarsh site.

Eight plant species, *A. stipoides, G. filum, J. kraussii, S. repens, S. quinqueflora, S. radicans, S. australis* and *Tecticornia arbuscula,* have been selected for further analysis. This selection was based on being the best representatives of all eight vegetation communities (see Table 6.1) and displaying diverse overall and ecological ranges within many edaphic factors. The minimum, quartiles (1st, 2nd, 3rd) and maximum values of and are presented in Table 6.4 below (note: a full table for all twelve plant species is available in Appendix 6A.1).

Table 6.4: Minimum, 1st, 2nd and 3rd quartile, and maximum values by plant species (eight of the 12 statistically analysed) by each edaphic factor. The areas shaded light green are the edaphic factor ranges (inter-quartile range) in which each species is found and is an indication of "ecological/best fit" for that species within that individual edaphic factor. Edaphic factors are grouped by relevance to each other.

Factor	Plant species >	Aus_ sti	Gah_ fil	Jun_ kra	Sam_ rep	Sar_ qui	Sel_ rad	Sua_ aus	Tec_ arb
LOI550 (%)	Minimum	0.81	3.78	1.26	1.26	0.81	2.66	2.32	1.77
	1st quartile	6.35	15.84	16.87	13.13	13.38	16.12	14.99	12.33
	Median	16.01	30.71	34.01	26.45	26.34	31.44	24.71	23.29
	3rd quartile	24.19	37.38	48.87	41.40	40.93	51.84	39.07	34.35
	Maximum	50.24	59.24	78.85	72.56	68.77	72.56	56.26	55.98
LOI850 (%)	Minimum	1.17	4.47	1.56	1.56	1.17	4.95	2.69	2.76
	1st quartile	9.60	17.61	19.76	15.16	15.66	19.16	17.91	15.36
	Median	18.05	33.08	35.98	30.40	31.39	34.83	28.16	28.65
	3rd quartile	28.12	41.33	52.64	46.66	45.45	55.20	44.65	39.09
	Maximum	52.70	67.32	80.65	75.82	72.79	76.55	59.80	62.47
Organic layer depth (cm)	Minimum	0.0	5.0	0.0	2.0	0.0	2.0	5.0	0.0
	1st quartile	9.0	10.0	12.0	10.0	10.0	12.0	11.0	10.0
	Median	11.0	15.0	19.0	18.0	15.0	18.0	15.0	13.0
	3rd quartile	15.0	29.0	34.0	31.0	25.0	31.0	28.0	20.0
	Maximum	20.0	45.0	45.0	45.0	42.0	45.0	40.0	35.0
pH	Minimum	4.66	4.99	4.36	4.75	4.45	3.86	5.40	5.10
	1st quartile	6.02	5.84	5.59	5.72	5.77	5.38	6.44	6.23
	Median	6.46	6.22	5.97	6.18	6.18	5.96	6.68	6.57
	3rd quartile	7.26	6.60	6.43	6.66	6.67	6.49	7.23	7.09
	Maximum	8.17	7.63	7.63	8.05	8.00	8.00	7.87	8.15
EC (dS/m)	Minimum	0.80	2.27	0.40	0.40	0.79	1.16	4.43	4.11
	1st quartile	3.02	6.23	7.23	7.90	9.66	3.86	9.38	11.97
	Median	5.41	17.23	14.88	19.15	22.08	11.86	26.82	22.75
	3rd quartile	12.10	26.38	25.25	30.22	34.28	25.27	34.13	34.13
	Maximum	25.58	54.15	46.37	54.15	65.90	44.67	55.52	63.77
Moisture by volume (%)	Minimum	5.54	35.76	25.22	30.00	23.36	18.72	41.27	41.96
	1st quartile	33.70	60.55	60.53	60.42	58.57	56.55	60.55	64.86
	Median	58.57	71.94	75.90	77.28	73.34	72.85	74.00	74.17
	3rd quartile	71.32	83.17	84.15	84.76	82.57	82.59	81.53	81.53
	Maximum	85.75	91.89	98.60	96.00	98.50	96.00	91.71	91.71
Soil bulk density (g/cm^3)	Minimum	0.14	0.12	0.08	0.08	0.08	0.11	0.12	0.13
	1st quartile	0.56	0.19	0.17	0.19	0.19	0.17	0.19	0.23
	Median	0.67	0.42	0.24	0.28	0.33	0.25	0.31	0.40
	3rd quartile	0.94	0.69	0.55	0.54	0.64	0.57	0.59	0.63
	Maximum	1.39	1.13	1.13	1.00	1.23	1.15	1.13	1.02

Species names: Aus_sti = *Austrostipa stipoides,* Gah_fil = *Gahnia filum,* Jun_kra = *Juncus kraussii,* Sam_rep = *Samolus repens,* Sar_qui = *Sarcocornia quinqueflora,* Sel_rad = *Selliera radicans,* Sua_aus = *Suaeda australis,* Tec_arb = *Tecticornia arbuscula*.

Note: for the following text, values following species names have been drawn from Table 6.4 (above) and reflect the interquartile range with the median. Where two values are shown (e.g. 17-49), these indicate the 1st and 3rd quartiles, where three values are shown (e.g. 17-34-49), they reflect the 1st quartile, median and 3rd quartile. For example, *J. kraussii* (in LOI550) – 17 (1st quartile), 34 (median), 49 (3rd quartile). All values are expressed to the nearest whole number except for pH and soil bulk density where values are expressed to the 2nd decimal point.

The above table displays the range of values for individual plant species for individual edaphic factors. There appears, in several cases, paired or three-way relationships of interquartile values between some species. For example, the LOI550 range for *G. filum* (16-37) is analogous with *S. australis* (15-39), *S. repens* (13-41) is similar to *S. quinqueflora* (15-41), and still within the same category, *J. kraussii* (16-49) corresponds with that of *S. radicans* (16-52). However, a key difference of these species pairs is dissimilarity of the medians, where in the case of *G. filum* (31) is different to *S. australis* (25), *J. kraussii* (34) is different to *S. radicans* (31); and similarity of medians, where both *S. repens* and *S. quinqueflora* display similar medians (26). Interestingly, *S. repens* and *S. quinqueflora* together form one vegetation community (AQR), while the other species are members of similar and different communities.

Another example is moisture by volume. Here, *G. filum, J. kraussii* and *S. repens* each have a similar range (60-83/84), yet *G. filum* exhibits a median of 72, while the other species express a median of 76/77. In the case of *S. repens* (60-77-85) and *S. quinqueflora* (59-73-83), both display a somewhat similar a similar range, however a dissimilar median, yet are key species of vegetation community AQR. Likewise, in EC, both species exhibit dissimilar ranges and medians, *S. repens* (8-19-30) and *S. quinqueflora* (10-22-34). However, in respect of pH, *S. repens* (5.72-6.18-6.66) and *S. quinqueflora* (5.77-6.18-6.67) display a strong similar pattern. This suggests that LOI550 and pH, as a combination, appear to be possible determinants of plant species presence (or absence) in coastal saltmarshes.

From the above, it is obvious that in many cases the use of an individual edaphic factor as an indicator of plant species presence and coexistence must be handled with caution. It may be prudent to use two or more factors to consider plant species presence or suitability in restoration.

Plant species similarities/ dissimilarities (Tukey groups)

Plant species means, standard error, minimums and maximums along with Tukey groups are presented in Table 6.5. Table is ordered by plant species name.

Table 6.5: Plant species means, standard deviation, standard error, range and Tukey groups for all edaphic factors. The mean values followed by the same letter (Tukey group) are not different at p<0.05. Edaphic factors are grouped by relevance to each other.

Edaphic factor	Plant species	*n*	Mean	Std Error	Min	Max	Tukey group
LOI550 (%)	*Apodasmia brownii*	28	38.37 ±	3.52	1.44	68.77	a
	Austrostipa stipoides	50	18.30 ±	2.01	0.81	59.24	d
	Disphyma crassifolium	33	23.67 ±	2.40	3.60	55.98	bcd
	Gahnia filum	54	29.39 ±	2.22	3.78	59.24	abcd
	Hemichroa pentandra	33	32.40 ±	3.12	5.92	68.77	abc
	Juncus kraussii	163	33.51 ±	1.50	1.26	78.85	ab
	Samolus repens	108	28.14 ±	1.78	1.26	72.56	abcd
	Sarcocornia blackiana	22	16.21 ±	2.10	1.19	32.16	d
	Sarcocornia quinqueflora	272	27.45 ±	1.02	0.81	68.77	abcd
	Selliera radicans	70	33.75 ±	2.44	2.66	72.56	ab
	Suaeda australis	26	26.96 ±	2.63	2.32	56.26	abcd
	Tecticornia arbuscula	57	23.22 ±	1.87	1.77	55.98	cd
LOI850 (%)	*Apodasmia brownii*	28	41.08 ±	3.66	1.78	72.79	a
	Austrostipa stipoides	50	20.89 ±	2.10	1.17	62.56	c
	Disphyma crassifolium	33	26.99 ±	2.59	5.01	62.47	bc
	Gahnia filum	54	32.21 ±	2.40	4.47	67.32	abc
	Hemichroa pentandra	33	35.26 ±	3.32	6.58	72.79	ab
	Juncus kraussii	163	36.69 ±	1.56	1.56	80.65	ab
	Samolus repens	108	31.61 ±	1.87	1.56	75.82	abc
	Sarcocornia blackiana	22	19.45 ±	2.29	4.37	39.09	c
	Sarcocornia quinqueflora	272	31.32 ±	1.09	1.17	72.79	abc
	Selliera radicans	70	36.82 ±	2.50	4.95	76.55	ab
	Suaeda australis	26	30.36 ±	2.79	2.69	59.80	abc
	Tecticornia arbuscula	57	27.29 ±	2.10	2.76	62.47	bc
Organic layer depth (cm)	*Apodasmia brownii*	28	28.57 ±	2.16	7.00	45.00	a
	Austrostipa stipoides	50	13.28 ±	1.15	0.00	35.00	de
	Disphyma crassifolium	33	11.48 ±	1.16	2.00	32.00	de
	Gahnia filum	54	18.87 ±	1.48	5.00	45.00	bcd
	Hemichroa pentandra	33	16.42 ±	1.23	5.00	33.00	cde
	Juncus kraussii	163	22.18 ±	0.98	0.00	45.00	ab
	Samolus repens	108	19.81 ±	1.14	2.00	45.00	bc
	Sarcocornia blackiana	22	9.23 ±	1.11	0.00	25.00	e
	Sarcocornia quinqueflora	272	17.24 ±	0.63	0.00	42.00	cde
	Selliera radicans	70	20.23 ±	1.32	2.00	45.00	bc
	Suaeda australis	26	18.73 ±	1.96	5.00	40.00	bcde
	Tecticornia arbuscula	57	15.81 ±	1.19	0.00	36.00	cde

Edaphic factor	Plant species	*n*	Mean		Std Error	Min	Max	Tukey group
pH	*Apodasmia brownii*	28	5.83	±	0.09	4.66	6.60	c
	Austrostipa stipoides	50	6.55	±	0.12	4.66	8.17	ab
	Disphyma crassifolium	33	6.10	±	0.16	4.51	7.77	bc
	Gahnia filum	54	6.29	±	0.08	4.99	7.93	abc
	Hemichroa pentandra	33	6.18	±	0.10	4.94	7.23	bc
	Juncus kraussii	163	6.06	±	0.06	4.01	8.04	c
	Samolus repens	108	6.24	±	0.08	3.86	8.13	bc
	Sarcocornia blackiana	22	6.37	±	0.20	4.92	8.17	abc
	Sarcocornia quinqueflora	272	6.26	±	0.05	4.45	8.36	bc
	Selliera radicans	70	5.98	±	0.11	3.86	8.00	c
	Suaeda australis	26	6.79	±	0.11	5.40	7.87	a
	Tecticornia arbuscula	57	6.68	±	0.09	5.10	8.15	a
EC (dS/m)	*Apodasmia brownii*	28	17.26	±	2.14	0.48	43.31	cd
	Austrostipa stipoides	50	9.83	±	1.42	0.80	49.43	d
	Disphyma crassifolium	33	17.87	±	2.83	1.53	64.63	bcd
	Gahnia filum	54	17.81	±	1.71	2.27	54.15	bcd
	Hemichroa pentandra	33	31.38	±	2.66	5.76	56.29	a
	Juncus kraussii	163	17.47	±	0.98	0.40	53.60	cd
	Samolus repens	108	20.10	±	1.32	0.40	54.15	bc
	Sarcocornia blackiana	22	11.46	±	1.84	1.53	26.94	cd
	Sarcocornia quinqueflora	272	23.67	±	0.97	0.79	65.90	abc
	Selliera radicans	70	15.20	±	1.53	1.16	44.67	cd
	Suaeda australis	26	23.95	±	2.68	4.43	55.52	abc
	Tecticornia arbuscula	57	25.36	±	2.07	4.11	63.77	ab
Moist by volume (%)	*Apodasmia brownii*	28	76.76	±	2.54	37.60	98.50	a
	Austrostipa stipoides	50	52.17	±	3.09	5.54	85.75	c
	Disphyma crassifolium	33	55.89	±	3.70	16.73	94.71	bc
	Gahnia filum	54	70.43	±	1.87	35.76	91.89	a
	Hemichroa pentandra	33	76.87	±	2.39	32.06	94.68	a
	Juncus kraussii	163	71.02	±	1.41	11.34	98.60	a
	Samolus repens	108	72.27	±	1.62	30.00	96.00	a
	Sarcocornia blackiana	22	49.67	±	4.42	16.73	82.60	c
	Sarcocornia quinqueflora	272	68.68	±	1.10	15.29	98.50	ab
	Selliera radicans	70	66.26	±	2.41	18.72	96.00	ab
	Suaeda australis	26	70.18	±	2.72	41.27	91.71	ab
	Tecticornia arbuscula	57	72.41	±	1.78	34.94	91.71	a

Edaphic factor	Plant species	*n*	Mean	Std Error	Min	Max	Tukey group
Soil bulk density (g/cm^3)	*Apodasmia brownii*	28	0.31 ±	0.04	0.10	0.88	c
	Austrostipa stipoides	50	0.71 ±	0.04	0.14	1.39	a
	Disphyma crassifolium	33	0.60 ±	0.05	0.12	1.43	ab
	Gahnia filum	54	0.48 ±	0.04	0.12	1.13	abc
	Hemichroa pentandra	33	0.34 ±	0.04	0.14	0.97	c
	Juncus kraussii	163	0.40 ±	0.03	0.08	1.47	c
	Samolus repens	108	0.43 ±	0.03	0.08	1.43	bc
	Sarcocornia blackiana	22	0.74 ±	0.07	0.27	1.43	a
	Sarcocornia quinqueflora	272	0.46 ±	0.02	0.08	1.56	bc
	Selliera radicans	70	0.39 ±	0.04	0.11	1.15	c
	Suaeda australis	26	0.42 ±	0.06	0.12	1.13	bc
	Tecticornia arbuscula	57	0.47 ±	0.04	0.13	1.43	bc

LOI550 (4 levels of difference): all plant species except for *A. stipoides, D. crassifolium, S. blackiana* and *T. arbuscula* displayed common means (Tukey group **a**); all species except for *A. brownii, A. stipoides, S. blackiana* and *T. arbuscula* formed group **b**; all plant species except for *A. brownii, A. stipoides, J. kraussii, S. blackiana* and *S. radicans* were not significantly different in terms of means (**c**), while all species with the exception of *A. brownii, H. pentandra, J. kraussii* and *S. radicans* exhibited similar means (group **d**).

LOI850 (3 levels of difference): all plant species except for *A. stipoides, D. crassifolium, S. blackiana* and *T. arbuscula* had common means (Tukey group **a**); all species except for *A. brownii, A. stipoides* and *S. blackiana* formed group **b**, while all species apart from *A. brownii, H. pentandra, J. kraussii* and *S. radicans* displayed similar means (group **c**).

Mean LOI values were varied two-fold, for example, LOI550: *S. blackiana* 16.21 ± 2.10 to *S. radicans* 33.75 ± 2.44. A large difference existed between congenors *S. blackiana* and *S. quinqueflora,* (16.21 ± 2.10 and 27.45 ± 1.02 respectively), yet the two species were frequently found together in the field (e.g. in vegetation communities AGH, AHM, AHR and ASH). The greatest range was exhibited by *J. kraussii* (1.26-78.85), followed by *S. radicans* (2.66-72.56). *D. crassifolium* displayed the smallest LOI spread with *S. australis* the next smallest (52.38 and 53.94 respectively).

Organic layer depth (5 levels of difference): significant differences occurred within this edaphic factor. Two plant species, *A brownii* and *J. kraussii* had similar means (group **a**); *G. filum, J. kraussii, S. repens, S. radicans* and *S. australis* were similar in terms of means (Tukey group **b**); *G. filum, H. pentandra, S. repens, S. quinqueflora, S. radicans, S. australis* and *T. arbuscula* exhibited similar means (group **c**); all species except for *A. brownii, J. kraussii, S. repens, S. blackiana* and *S. radicans* displayed similarity in terms of means (group **d**), while all species except for *A. brownii, G. filum, J. kraussii, S. repens* and *S. radicans* formed the final group (**e**).

Mean organic layer depths were varied three-fold, *S. blackiana* at 9.23 ± 1.11 to *A. brownii* at 28.57 ± 2.16; *A. brownii* also had the greatest organic layer depth (28.57 ± 1.11) followed by *J. kraussii* (22.18 ± 0.98). Again, like LOI treatments, congenors *S. blackiana* (9.23 ± 1.11) and *S. quinqueflora* (17.24 ± 0.63) exhibited a two-fold variation, an expected result (deeper the organic layer, higher the LOI value). Species *J. kraussii* recorded the greatest range (0.00-45.00, 45), followed by *S. repens* and *S. radicans* (both 2.00-45.00, 43). *S. blackiana* displayed the smallest organic depth range (0.00-25.00, 25).

pH (3 levels of difference): *A. stipoides, G. filum, S. blackiana, S. australis* and *T. arbuscula* recorded similar means and formed group **a**; all species except for *A. brownii, J. kraussii, S. radicans, S. australis* and *T. arbuscula* displayed similarity in terms of means (Tukey group **b**), while types all plant species with the exception of *A. stipoides, S. australis* and *T. arbuscula* exhibited similar means (**c**).

Mean pH values varied nearly a full unit, *A brownii* (5.83 ± 0.09) (most acid tolerant species) to *S. australis* (6.79 ± 0.11) (the least acid tolerant species). Two species, *S. repens* and *S. radicans*, tolerated the largest pH range (3.86 to 8.13 and 3.86 to 8.00 respectively), while *A. brownii* was the least tolerant species (4.66 to 6.60) in terms of pH range. Congenors *S. blackiana* and *S. quinqueflora* displayed close means (6.37 ± 0.20 and 6.26 ± 0.05 respectively) but different ranges (4.92-8.17, 3.25 and 4.45-8.36, 3.91 respectively).

EC (4 levels of difference): four species, *H. pentandra, S. quinqueflora, S. australis* and *T. arbuscula* displayed similarity in terms of means (Tukey group **a**); *D. crassifolium, G. filum, S. repens, S. quinqueflora, S. australis* and *T. arbuscula* exhibited similar means

(group **b**); all plant species except for *A. stipoides, H. pentandra* and *T. arbuscula* recorded commonality in terms of means (group **c**), while all species with the exception of *H. pentandra, S. repens, S. quinqueflora, S. australis* and *T. arbuscula* were similar (**d**).

Mean EC values varied nearly three-fold, *A. stipoides* (9.83 ± 1.42), the least salt tolerant species, to *T. arbuscula* (25.36 ± 2.07), being the most salt tolerant species. *S. quinqueflora* exhibited the greatest EC range (0.79-65.90, 65.11), followed by *D. crassifolium* (1.53-64.63, 63.10). There was a two-fold variation between congenors *S. blackiana* (11.46 ± 1.84) and *S. quinqueflora* (23.67 ± 0.97), yet, the tolerable range of *S. blackiana* (1.53-26.94, (25.41) was far less than half that of *S. quinqueflora* (0.79 to 65.90, 65.11).

Moisture by volume (3 levels of difference): all plant species expect for *A. stipoides, D. crassifolium* and *S. blackiana* recorded similarity in terms of means (group **a**); species *D. crassifolium, S. quinqueflora, S. radicans* and *S. australis* had similar means (Tukey group **b**), while *A. stipoides, D. crassifolium* and *S. blackiana* displayed no significant difference to each other (group **c**).

Mean moisture values differed by 0.5-fold, *S. blackiana* (49.67 ± 4.42) to *H. pentandra* (76.87 ± 2.39). Of all plant species, *J. kraussii* tolerated the greatest moisture (range 11.34-98.60, 87.26), while *S. australis* had the least tolerance to moisture variations (range 41.27-91.71, 50.44). Congenors *S. blackiana* and *S. quinqueflora* displayed a difference in mean moisture of 38%, with *S. blackiana* occupying a narrower range (16.73-82.60, 65.8) than *S. quinqueflora* (15.29-98.50, 83.21).

Bulk density (3 levels of difference): four species, *A. stipoides, D. crassifolium, G. filum* and *S. blackiana* displayed similar means (group **a**); *D. crassifolium, G. filum, S. repens, S. quinqueflora, S. australis* and *T arbuscula* exhibited commonality in terms of means (**b**), while all species except for *A. stipoides, D. crassifolium* and *S. blackiana* were similar in terms of means (Tukey group **c**).

Mean soil bulk density values varied more than two-fold, *A. brownii* (0.31 ± 0.04) to *S. blackiana* (0.74 ± 0.07). Plant species *S. quinqueflora* tolerated the greatest range of soil bulk density (0.08-1.56, 1.48), whereas *G. filum* and *S. australis* displayed tolerance for the smallest bulk density range (0.12-1.13, 1.01). In respect of congenors *S. blackiana* and *S. quinqueflora*, there was a 0.50-fold variation in bulk density means

(0.74 ± 0.07, 0.46 ± 0.02 respectively), while *S. quinqueflora* recorded a greater range (0.08-1.56, 1.48) compared to *S. blackiana* (0.27-1.43, 1.16).

Summary – plant species and edaphic factors

Four of the edaphic factors, LOI850, pH, moisture by volume and bulk density display three levels of dissimilarity, yet, between them, none have species in common with various Tukey groups. This is similar for LOI550 and EC, both with four levels of difference. Organic layer depth has five levels of difference and could be a measure of difference between plants species, or combinations of species, however, when examining the interquartile ranges (Table 6.5), there is little variation between species, though several species display dissimilar median values.

6.4.2 Plant species and climate variables

Descriptive charts

Charts of plant species fitted against key climate variables: a) mean annual rainfall, highest annual rainfall and lowest annual rainfall (Figures 6.15 to 6.17); b) mean annual maximum and minimum temperatures, and highest maximum and lowest minimum annual temperatures, are presented in Figures 6.18 to 6.21; and c) mean highest and lowest daily solar exposure Figures 6.22 and 6.23).

Rainfall variables

The following charts demonstrate in a graphical format the tolerance range of plant species to mean annual rainfall, and the highest and lowest annual rainfall recorded.

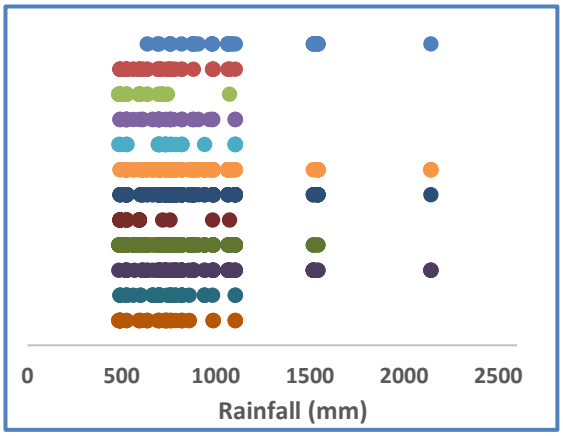

Figure 6.15: Plant species mean annual rainfall.

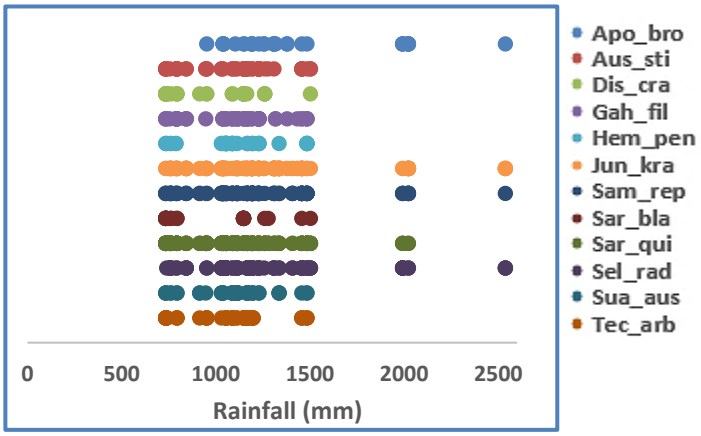

Figure 6.16: Plant species highest annual rainfall.

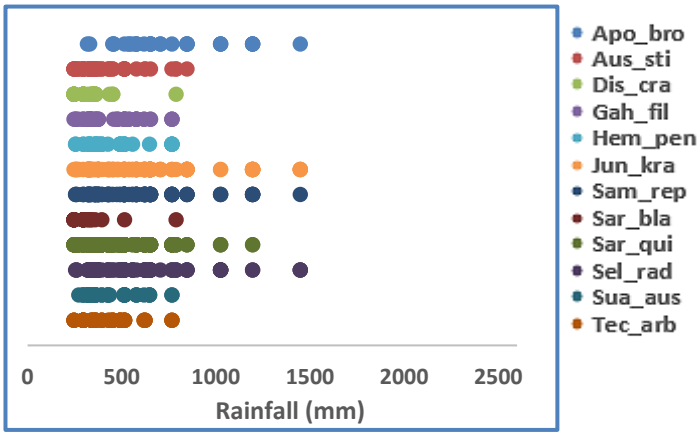

Figure 6.17: Plant species lowest annual rainfall.

Most plant species were constrained within the greatest range of mean annual rainfall and highest annual rainfall (Figures 6.15 and 6.16), however, *A. brownii, J. kraussii, S. repens* and *S. radicans* displayed a greater tolerance for wetter conditions. In respect of lowest annual rainfall (Figure 6.17), the same four species still exhibited presence in the higher realm of precipitation with *D. crassifolium* and *S. blackiana* displaying a limited range and positioned at the lower spectrum of the variable. These two species appeared less tolerant to higher rainfall; however, the lower number of plots in which the two species were present suggests caution around this conclusion. Care must be taken when interpreting the rainfall charts as there appears several outliers in the data, this may be due to few plots recorded with individual species especially at the higher end of the data range. However, the charts do provide a good indication of the tolerance range of individual plants species to rainfall.

Temperature variables

The following charts (Figures 6.18 to 6.21) demonstrate the tolerance range of plant species to mean annual maximum and minimum temperatures, and the highest maximum and lowest minimum annual temperatures recorded by plant species. Chart legends are ordered by plant species name.

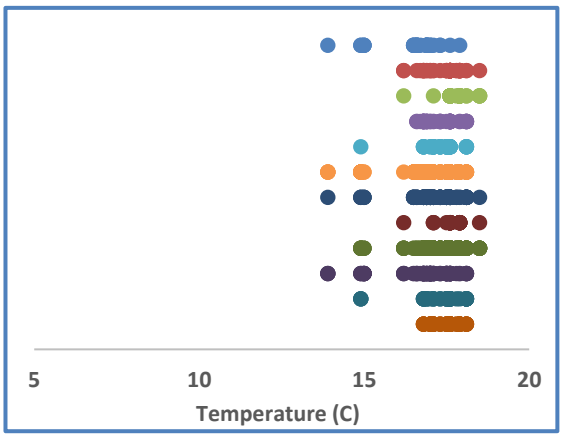

Figure 6.18: Plant species mean annual maximum temperature.

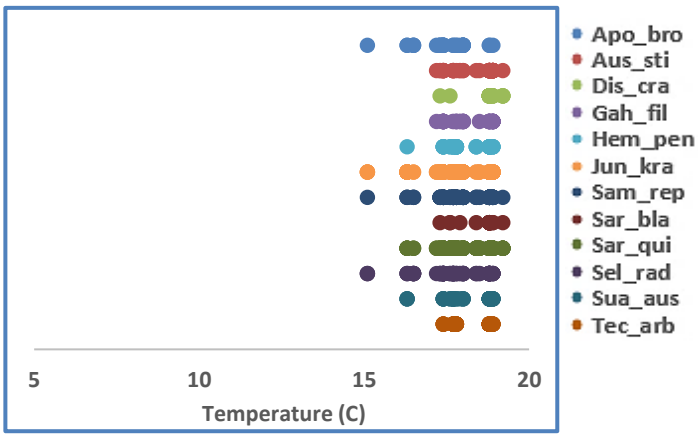

Figure 6.19: Plant species highest annual maximum temperature.

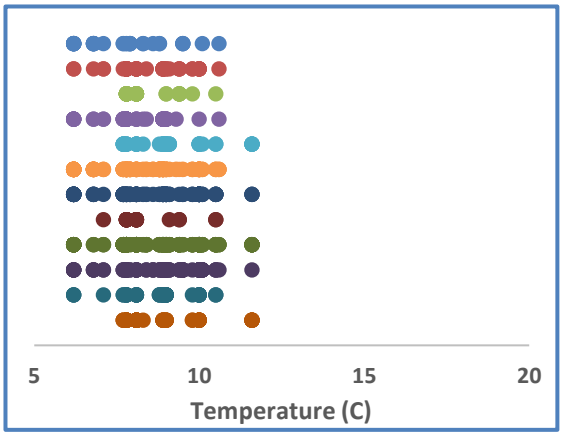

Figure 6.20: Plant species mean annual minimum temperature.

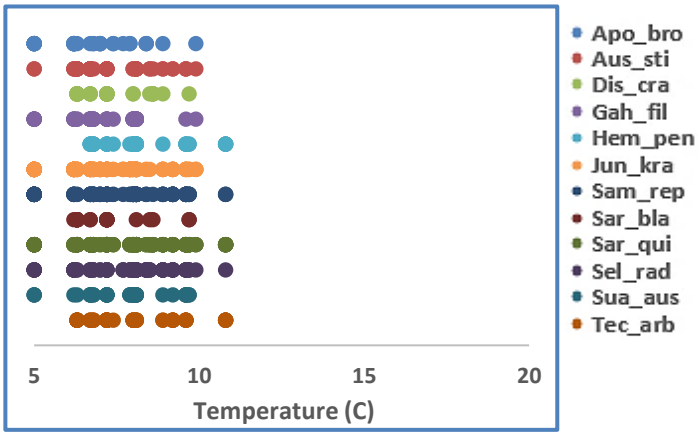

Figure 6.21: Plant species and lowest annual minimum temperature recorded.

These results indicated that temperature preforms a somewhat limited role in individual plant species presence. Species *A. brownii* prefers a lower mean annual maximum and minimum temperatures and this species also has less tolerance for high maximum temperatures. Conversely, *T. arbuscula* tolerated higher mean annual maximum and minimum temperatures and a high recorded maximum annual temperature. However, most plant species appear in the full range of temperatures – maximums and minimums.

Solar exposure variables

The following charts (Figure 6.22 and 6.23) displays the tolerance range of individual plant species to mean highest and lowest daily solar exposure.

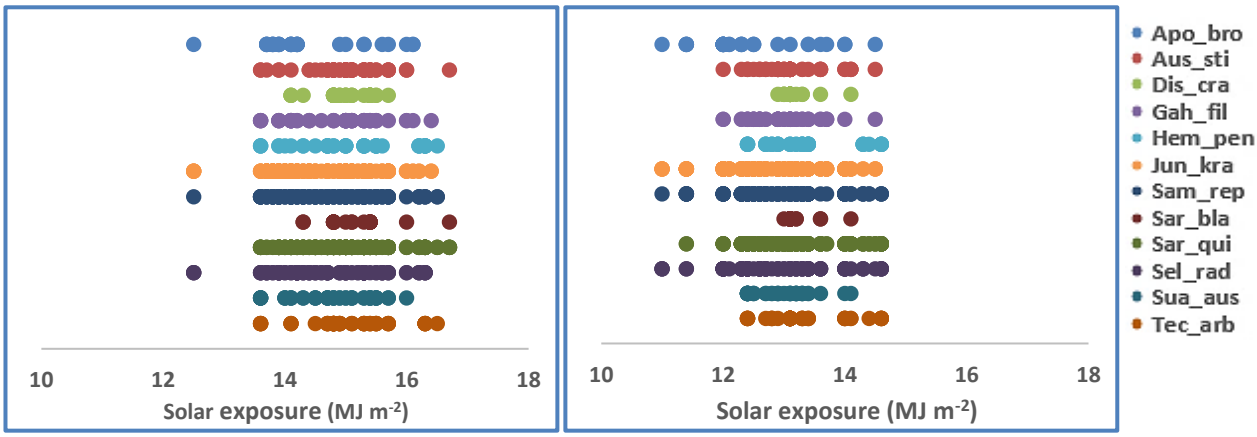

Figure 6.22: Plant species mean highest daily solar exposure.

Figure 6.23: Plant species mean lowest daily solar exposure.

Four species, *A. brownii, J. kraussii, S. repens* and *S. radicans* were found in the greatest range of daily solar exposure – 11.0 to 16.5 per day, followed by *S. quinqueflora* (11.4 to 16.5) indicating that solar exposure is less of a contributing variable to plant species presence in the landscape. One species, *D. crassifolium*, had the most limited range (12.9 to 15.7), followed by *S. blackiana* (13.0 to 16.7). These two species displayed far less tolerance to this climate variable than do the remaining plant species. Most plant species were found within the greatest range of solar exposure (12.0 to 16.7).

ANOVA

Plant species climate variables ANOVA outputs are presented in Table 6.6.

Table 6.6: ANOVA outputs of all assessed climate variables. The climate variable order is by graphical display charts (above) and grouped to relevance (those variables that have commonality).

Variable	Df	F value	p-value	
Mean annual rainfall (mm)	11, 904	15.750	<2e-16	***
Highest annual rainfall recording (mm)	11, 904	9.858	<2e-16	***
Lowest annual rainfall recording (mm)	11, 904	16.760	<2e-16	***
Mean annual maximum temperature (°C)	11, 904	14.180	<2e-16	***
Mean annual minimum temperature (°C)	11, 904	6.415	2.59e-10	***
Highest maximum annual temperature (°C)	11, 904	12.800	<2e-16	***
Lowest minimum annual temperature (°C)	11, 904	6.250	5.26e-10	***
Mean highest daily solar exposure (MJ/m^2)	11, 904	7.733	6.93e-13	***
Mean lowest daily solar exposure (MJ/m^2)	11, 904	9.038	1.91e-15	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. **Df** = degrees of freedom.

All climate variables displayed a highly significant difference between plant species within each climate variable. The very low p-values ($p<0.001$) indicated that at least one plant species within each climate variable was significantly different to all other plant species within that variable.

Boxplots

Boxplots of plant species fitted against key climate variables: a) mean annual rainfall. highest annual rainfall and lowest annual rainfall (Figures 6.24 to 6.26), b) mean annual maximum and minimum temperatures, and highest maximum and lowest minimum annual recorded temperatures, are presented in Figures 6.27 to 6.30, and c) mean highest and lowest daily solar exposure Figures 6.31 and 6.32).

The following boxplots display the distribution of each plant species across individual variables to show the minimum, 1st quartile, median, 3rd quartile and maximum of the data and convey the "ecological/best fit" range of tolerance of plant species to specific climate variables.

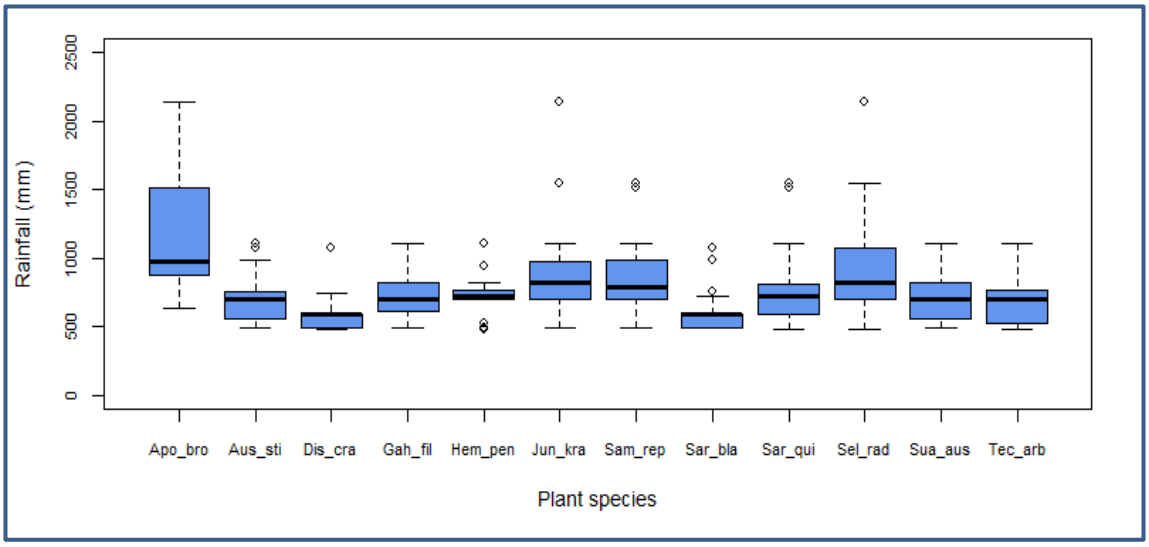

Figure 6.24: Boxplot of plant species and mean annual rainfall.

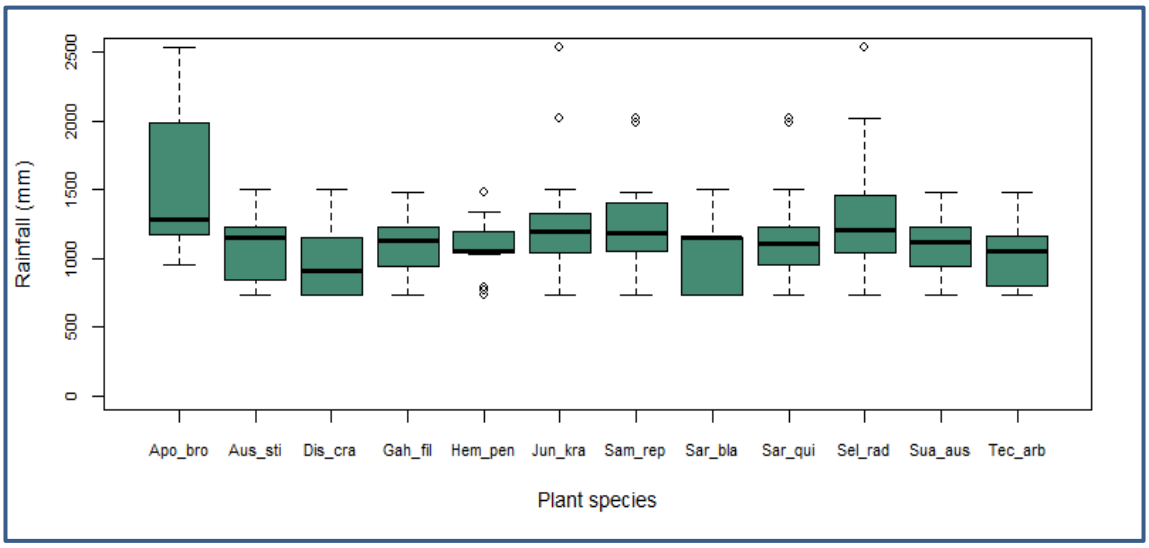

Figure 6.25: Boxplot of plant species and highest annual rainfall.

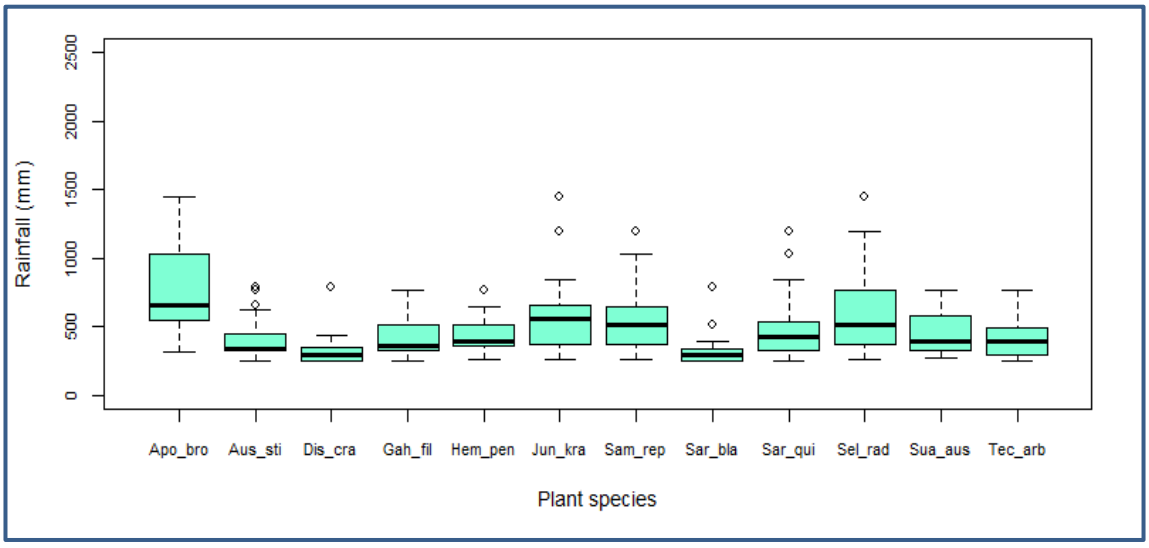

Figure 6.26: Boxplot of plant species and lowest annual rainfall.

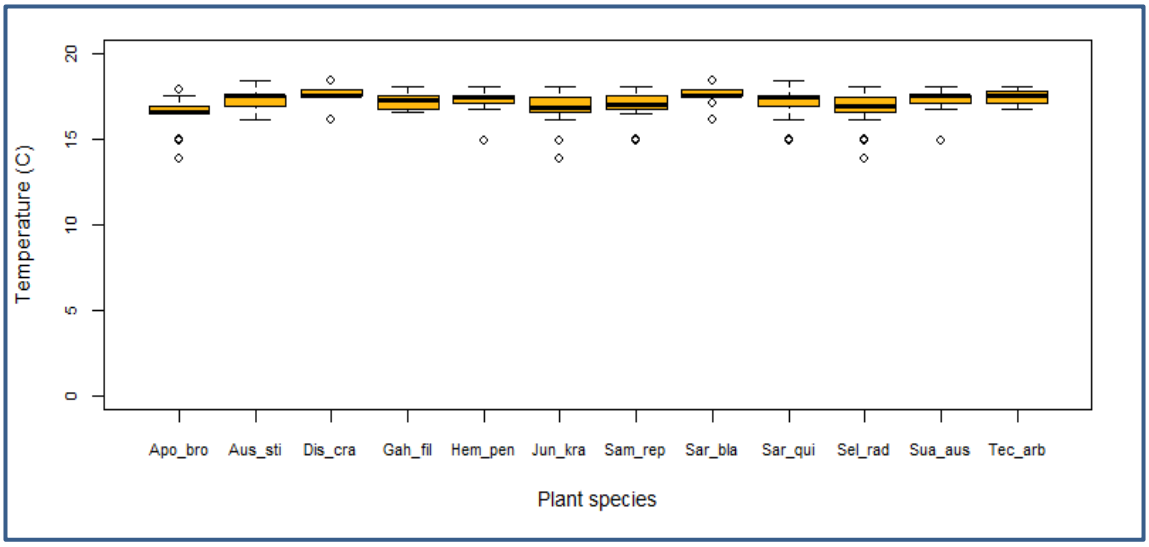

Figure 6.27: Boxplot of plant species and mean annual maximum temperature.

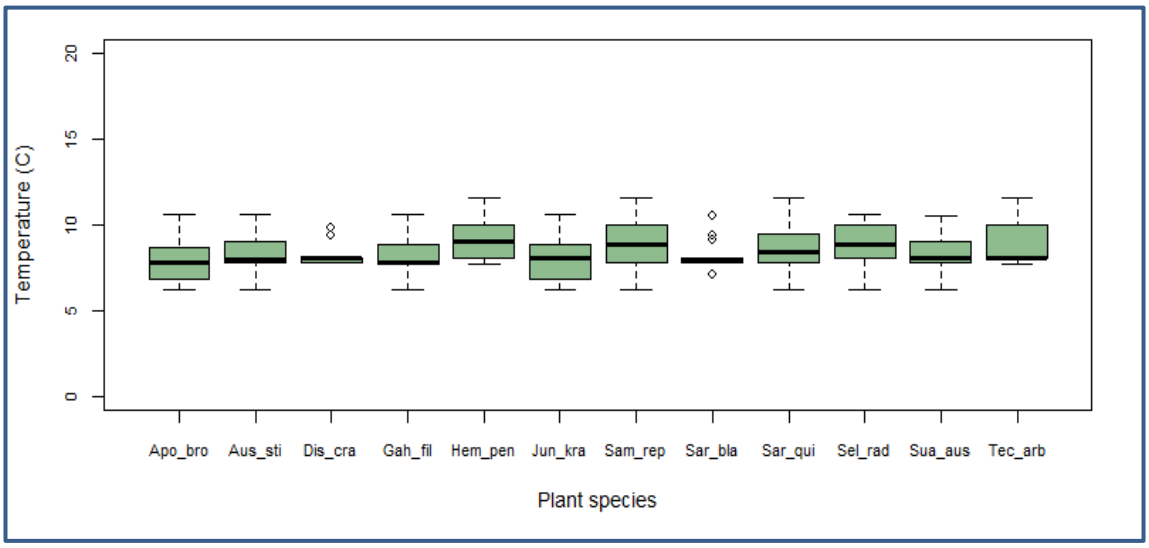

Figure 6.28: Boxplot of plant species and mean annual minimum temperature.

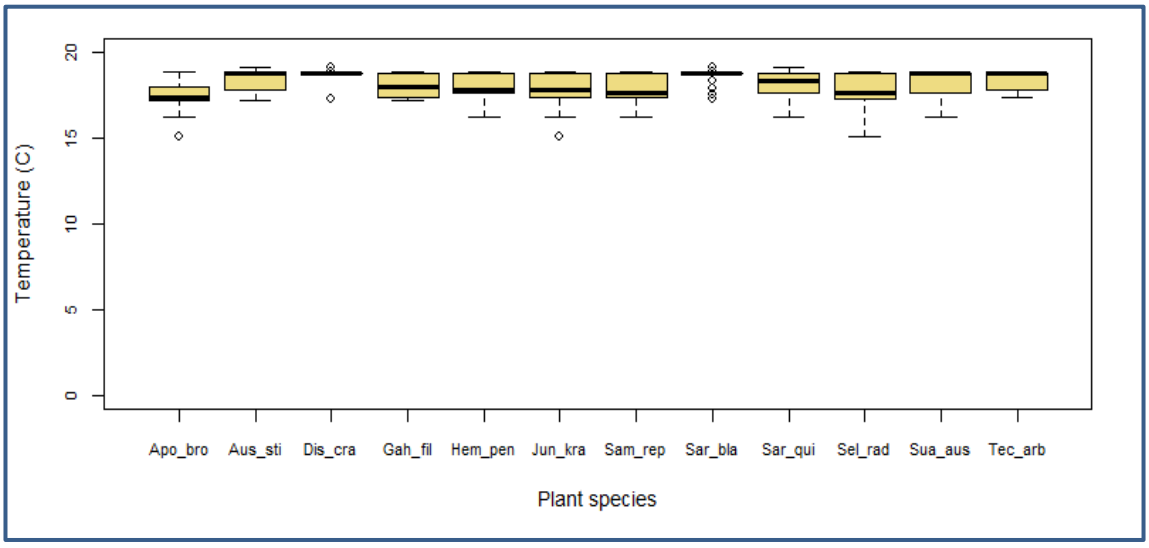

Figure 6.29: Boxplot of plant species and highest annual maximum temperature.

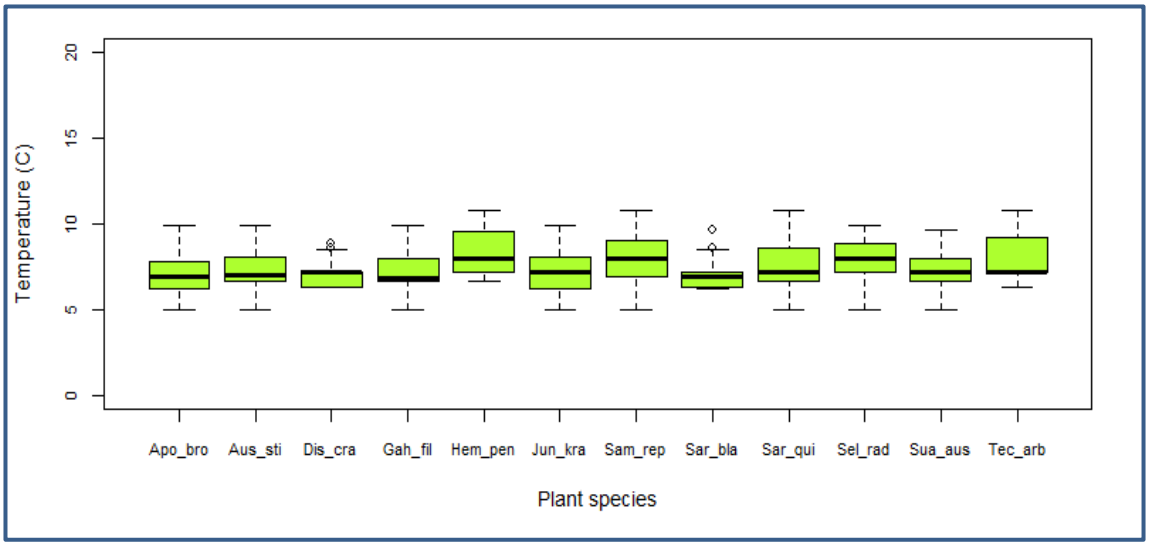

Figure 6.30: Boxplot of plant species and lowest annual minimum temperature.

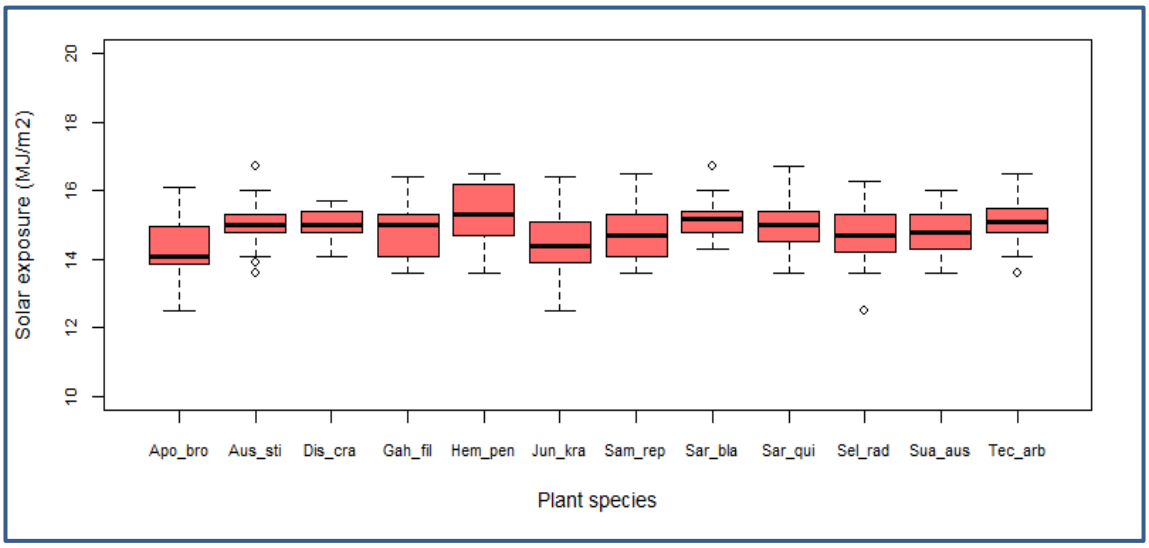

Figure 6.31: Boxplot of plant species and mean highest daily solar exposure.

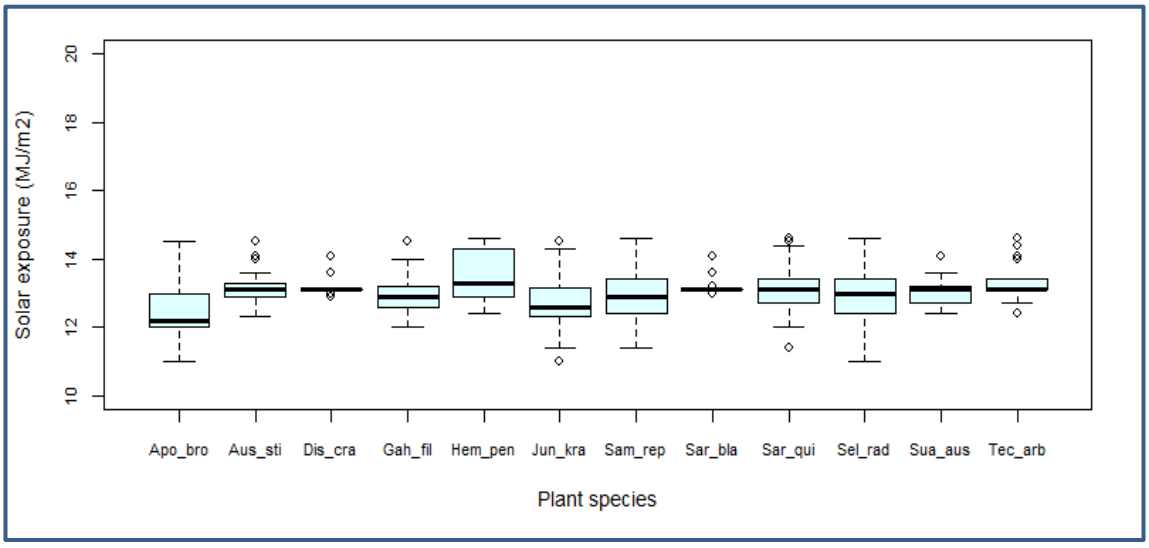

Figure 6.32: Boxplot of plant species and mean lowest daily solar exposure.

Plant species that display a large (tall) box, have a greater tolerance across the range of each climate variable. Examples include, *A. brownii* and *S. radicans* in mean annual, highest annual and lowest annual rainfall, and *G. filum, H. pentandra* and *J. kraussii* in highest mean daily solar exposure. Plant species that display a somewhat restricted range (have a lower tolerance across a range) within a climate variable include, *D. crassifolium* and *S. blackiana* in mean annual and lowest annual rainfall, mean minimum, highest annual maximum and lowest annual minimum temperatures and mean lowest daily solar exposure.

It is of interest to note that the tolerance ranges of four key species found in the mixed herb vegetation group (AHM) – *D. crassifolium, H. pentandra, S. repens* and *S. blackiana*. In many cases *D. crassifolium* and *S. blackiana* displayed a very limited range (e.g. mean annual and lowest rainfall), yet *H. pentandra* and *S. repens* exhibited a broader range each commencing above the extent of the range the other two species (Figures 6.24 and 6.26). This was also evident in mean annual minimum and lowest annual minimum temperatures (Figures 6.28 and 6.29). Mean highest and lowest daily solar exposure charts display a different viewpoint, where both *D. crassifolium* and *S. blackiana* exhibited similar ranges, yet *H. pentandra* extended beyond with increasing values (upwards) and *S. repens* continued beyond with decreasing values (downwards) (Figures 6.31 and 6.32). This demonstrates the complexity of plants species (individually and combined) tolerances to climate variables and the large variability in their habitats.

Similar to that of edaphic factors, by reviewing each boxplot in turn, and selecting species that display the greatest range within each climate variable and then overall, we are able to identify species that could serve as "pioneer" plants suitable for saltmarsh restoration.

The minimum, quartiles (1st, 2nd, 3rd) and maximum values for eight (of 12) plant species – these species chosen as representative of all vegetation communities (see Table 6.1) – are presented in Table 6.7 (a full table is available in Appendix 6A.2).

Table 6.7: Minimum, 1st, 2nd and 3rd quartile, and maximum values by eight (of 12) plant species (of those statistically analysed) by each climate variable. The areas shaded light green are the climate variable ranges (the inter-quartile range) in which each species is found and is an indication of the "ecological/best fit" for that species within that individual climate variable. The climate variables are grouped by relevance to each other.

Climate variable	Plant species >	Aus_ sti	Gah_ fil	Jun_ kra	Sam_ rep	Sar_ qui	Sel_ rad	Sua_ aus	Tec_ arb
Mean annual rainfall (mm)	Minimum	492	492	492	492	485	485	492	485
	1st quartile	561	610	700	704	593	700	561	525
	Median	700	700	820	793	728	819	704	696
	3rd quartile	758	820	979	987	806	1073	820	762
	Maximum	987	1104	1104	1104	1104	1543	1104	1104
Highest annual rainfall (mm)	Minimum	735	735	735	735	735	739	735	735
	1st quartile	844	947	1039	1049	952	1043	947	795
	Median	1148	1133	1192	1180	1109	1212	1118	1056
	3rd quartile	1229	1229	1328	1408	1229	1458	1229	1168
	Maximum	1504	1484	1504	1484	1504	2024	1484	1484
Lowest annual rainfall (mm)	Minimum	247	247	256	256	247	260	273	247
	1st quartile	330	330	376	375	330	376	322	297
	Median	338	363	558	515	427	516	395	395
	3rd quartile	452	516	654	648	537	768	579	491
	Maximum	625	768	847	1026	847	1196	768	768
Mean annual maximum temperature (°C)	Minimum	16.2	16.6	16.2	16.5	16.2	16.2	16.8	16.8
	1st quartile	17.0	16.8	16.6	16.8	17.0	16.6	17.1	17.1
	Median	17.6	17.3	16.9	17.1	17.5	17.0	17.6	17.6
	3rd quartile	17.6	17.6	17.5	17.6	17.6	17.5	17.6	17.8
	Maximum	18.5	18.1	18.1	18.1	18.5	18.1	18.1	18.1
Mean annual minimum temperature (°C)	Minimum	6.2	6.2	6.2	6.2	6.2	6.2	6.2	7.7
	1st quartile	7.8	7.7	6.8	7.9	7.8	8.1	7.8	8.1
	Median	8.0	7.8	8.1	8.9	8.4	8.9	8.1	8.1
	3rd quartile	9.0	8.9	8.9	10.0	9.5	10.0	9.0	10.0
	Maximum	10.6	10.6	10.6	11.6	11.6	10.6	10.5	11.6
Highest annual maximum temperature (°C)	Minimum	17.2	17.2	16.3	16.3	16.3	15.1	16.3	17.4
	1st quartile	17.8	17.4	17.4	17.4	17.7	17.3	17.7	17.8
	Median	18.8	18.0	17.8	17.7	18.4	17.7	18.8	18.8
	3rd quartile	18.9	18.8	18.8	18.8	18.8	18.8	18.8	18.8
	Maximum	19.2	18.9	18.9	18.9	19.2	18.9	18.9	18.9
Lowest annual minimum temperature (°C)	Minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	6.3
	1st quartile	6.7	6.7	6.2	6.9	6.7	7.2	6.7	7.2
	Median	7.0	6.8	7.2	8.0	7.2	8.0	7.2	7.2
	3rd quartile	8.1	8.0	8.1	9.1	8.6	8.9	8.0	9.2
	Maximum	9.9	9.9	9.9	10.8	10.8	9.9	9.7	10.8

Climate variable	Plant species >	Aus_ sti	Gah_ fil	Jun_ kra	Sam_ rep	Sar_ qui	Sel_ rad	Sua_ aus	Tec_ arb
Mean highest daily solar exposure (MJ/m^2)	Minimum	14.1	13.6	12.5	13.6	13.6	13.6	13.6	14.1
	1st quartile	14.8	14.1	13.9	14.1	14.5	14.2	14.3	14.8
	Median	15.0	15.0	14.4	14.7	15.0	14.7	14.8	15.1
	3rd quartile	15.3	15.3	15.1	15.3	15.4	15.3	15.3	15.5
	Maximum	16.0	16.4	16.4	16.5	16.7	16.3	16.0	16.5
Mean lowest daily solar exposure (MJ/m^2)	Minimum	12.3	12.0	11.4	11.4	12.0	11.0	12.4	12.7
	1st quartile	12.9	12.6	12.3	12.4	12.7	12.4	12.7	13.1
	Median	13.1	12.9	12.6	12.9	13.1	13.0	13.1	13.1
	3rd quartile	13.3	13.2	13.2	13.4	13.4	13.4	13.2	13.4
	Maximum	13.6	14.0	14.3	14.6	14.4	14.6	13.6	13.4

Species names: Aus_sti = *Austrostipa stipoides,* Gah_fil = *Gahnia filum,* Jun_kra = *Juncus kraussii,* Sam_rep = *Samolus repens,* Sar_qui = *Sarcocornia quinqueflora,* Sel_rad = *Selliera radicans,* Sua_aus = *Suaeda australis,* Tec_arb = *Tecticornia arbuscula*.

Note for text below: values following species names have been drawn from Table 6.7 (above) and reflect the interquartile range with the median. Where two values are shown (e.g. 376-654), these indicate the 1st and 3rd quartiles, where three values are shown (e.g. 376-558-654), they reflect the 1st quartile, median and 3rd quartile. For example, *J. kraussii* (in lowest annual rainfall) – 376 (1st quartile), 558 (median), 654 (3rd quartile). All rainfall variables values are expressed to the nearest whole number and the remainder are expressed to the 1st decimal point.

In several cases there appears similarity between species. For example, in mean annual rainfall the range for *S. quinqueflora* (593-806) was similar to that of *S. australis* (561-820), with the means also comparable (728 and 704 respectively). The same applies to highest annual rainfall where *S. quinqueflora* (952-1229) was analogous to that of *S. australis* (947-1229), the means also being comparable (1109 and 1118 respectively). Mean annual maximum temperature provides an insight to grouping of species where *A. stipoides, S. quinqueflora, S. australis* and *T. arbuscula* all displayed similar ranges and means (17.0-17.6-17.6), *G. filum* and *S. repens* were similar (16.8-17.1-17.6) and *J. kraussii* and *S. radicans* were similar (16.6-16.9-17.5).

Again, from the above, similar to edaphic factors, it is clearly demonstrated that the use of a single climate variable as an indicator of an individual plant species presence must be handled with care.

Plant species similarities/ dissimilarities (Tukey groups)

Plant species means, standard deviation and standard errors, minimums and maximums along with interaction terms are presented in Table 6.8. Table ordered by species name.

Table 6.8: Plant species means, standard deviation, standard error, range and Tukey groups for all climate variables. The values followed by the same letter (Tukey group) are not different at p<0.05.

Climate variable	Plant species	*n*	Mean		Std Error	Min	Max	Tukey group
Mean annual rainfall (mm)	*Apodasmia brownii*	28	1099	±	69	636	2143	a
	Austrostipa stipoides	50	701	±	24	492	1104	cd
	Disphyma crassifolium	33	581	±	21	485	1073	d
	Gahnia filum	54	734	±	22	492	1104	cd
	Hemichroa pentandra	33	731	±	27	485	1104	cd
	Juncus kraussii	163	883	±	24	492	2143	b
	Samolus repens	108	856	±	24	492	1543	b
	Sarcocornia blackiana	22	606	±	33	492	1073	cd
	Sarcocornia quinqueflora	272	743	±	12	485	1543	c
	Selliera radicans	70	942	±	46	485	2143	ab
	Suaeda australis	26	732	±	36	492	1104	cd
	Tecticornia arbuscula	57	685	±	23	485	1104	cd
Highest annual rainfall (mm)	*Apodasmia brownii*	28	1456	±	80	952	2538	a
	Austrostipa stipoides	50	1092	±	34	735	1504	c
	Disphyma crassifolium	33	971	±	41	735	1504	c
	Gahnia filum	54	1104	±	29	735	1484	c
	Hemichroa pentandra	33	1079	±	35	735	1484	c
	Juncus kraussii	163	1235	±	27	735	2538	b
	Samolus repens	108	1225	±	30	735	2024	b
	Sarcocornia blackiana	22	1010	±	55	735	1504	c
	Sarcocornia quinqueflora	272	1104	±	15	735	2024	c
	Selliera radicans	70	1308	±	52	739	2538	ab
	Suaeda australis	26	1095	±	46	735	1484	c
	Tecticornia arbuscula	57	1033	±	30	735	1484	c
Lowest annual rainfall (mm)	*Apodasmia brownii*	28	758	±	56	318	1449	a
	Austrostipa stipoides	50	404	±	20	247	789	cd
	Disphyma crassifolium	33	319	±	17	247	789	d
	Gahnia filum	54	432	±	19	247	768	cd
	Hemichroa pentandra	33	444	±	24	256	768	cd
	Juncus kraussii	163	589	±	21	256	1449	b
	Samolus repens	108	553	±	22	256	1196	b
	Sarcocornia blackiana	22	324	±	26	247	789	cd
	Sarcocornia quinqueflora	272	461	±	11	247	1196	c
	Selliera radicans	70	617	±	35	260	1449	ab
	Suaeda australis	26	451	±	30	273	768	cd
	Tecticornia arbuscula	57	422	±	18	247	768	cd

Climate variable	Plant species	*n*	Mean		Std Error	Min	Max	Tukey group
Mean annual maximum temperature (°C)	*Apodasmia brownii*	28	16.44	±	0.18	13.9	17.9	d
	Austrostipa stipoides	50	17.43	±	0.07	16.2	18.5	ab
	Disphyma crassifolium	33	17.76	±	0.07	16.2	18.5	a
	Gahnia filum	54	17.29	±	0.06	16.6	18.1	b
	Hemichroa pentandra	33	17.36	±	0.10	14.9	18.1	ab
	Juncus kraussii	163	16.86	±	0.07	13.9	18.1	cd
	Samolus repens	108	17.10	±	0.07	14.9	18.1	bc
	Sarcocornia blackiana	22	17.61	±	0.10	16.2	18.5	ab
	Sarcocornia quinqueflora	272	17.33	±	0.04	14.9	18.5	b
	Selliera radicans	70	16.76	±	0.13	13.9	18.1	cd
	Suaeda australis	26	17.23	±	0.18	14.9	18.1	bc
	Tecticornia arbuscula	57	17.51	±	0.05	16.8	18.1	ab
Mean annual minimum temperature (°C)	*Apodasmia brownii*	28	7.82	±	0.24	6.2	10.6	c
	Austrostipa stipoides	50	8.35	±	0.14	6.2	10.6	bc
	Disphyma crassifolium	33	8.23	±	0.11	7.8	9.8	bc
	Gahnia filum	54	8.06	±	0.14	6.2	10.6	c
	Hemichroa pentandra	33	9.26	±	0.22	7.7	11.6	a
	Juncus kraussii	163	8.10	±	0.10	6.2	10.6	c
	Samolus repens	108	8.73	±	0.12	6.2	11.6	ab
	Sarcocornia blackiana	22	8.30	±	0.19	7.1	10.5	bc
	Sarcocornia quinqueflora	272	8.62	±	0.08	6.2	11.6	ab
	Selliera radicans	70	8.83	±	0.13	6.2	10.6	ab
	Suaeda australis	26	8.39	±	0.21	6.2	10.5	abc
	Tecticornia arbuscula	57	8.91	±	0.16	7.7	11.6	ab
Highest annual maximum temperature (°C)	*Apodasmia brownii*	28	17.45	±	0.16	15.1	18.9	e
	Austrostipa stipoides	50	18.42	±	0.09	17.2	19.2	ab
	Disphyma crassifolium	33	18.82	±	0.05	17.3	19.2	a
	Gahnia filum	54	18.18	±	0.09	17.2	18.9	bc
	Hemichroa pentandra	33	18.16	±	0.11	16.3	18.9	bcd
	Juncus kraussii	163	17.81	±	0.07	15.1	18.9	de
	Samolus repens	108	17.92	±	0.06	16.3	18.9	cde
	Sarcocornia blackiana	22	18.59	±	0.11	17.3	19.2	ab
	Sarcocornia quinqueflora	272	18.21	±	0.04	16.3	19.2	b
	Selliera radicans	70	17.76	±	0.12	15.1	18.9	de
	Suaeda australis	26	18.17	±	0.17	16.3	18.9	bcd
	Tecticornia arbuscula	57	18.36	±	0.07	17.4	18.9	ab

Climate variable	Plant species	*n*	Mean		Std Error	Min	Max	Tukey group
Lowest annual minimum temperature (°C)	*Apodasmia brownii*	28	6.85	±	0.25	5.0	9.9	c
	Austrostipa stipoides	50	7.33	±	0.16	5.0	9.9	bc
	Disphyma crassifolium	33	7.14	±	0.14	6.3	8.9	c
	Gahnia filum	54	7.06	±	0.15	5.0	9.9	c
	Hemichroa pentandra	33	8.38	±	0.24	6.7	10.8	a
	Juncus kraussii	163	7.15	±	0.11	5.0	9.9	c
	Samolus repens	108	7.85	±	0.13	5.0	10.8	ab
	Sarcocornia blackiana	22	7.17	±	0.23	6.2	9.7	bc
	Sarcocornia quinqueflora	272	7.66	±	0.09	5.0	10.8	ab
	Selliera radicans	70	7.89	±	0.14	5.0	9.9	ab
	Suaeda australis	26	7.45	±	0.24	5.0	9.7	abc
	Tecticornia arbuscula	57	7.97	±	0.19	6.3	10.8	Ab
Mean highest daily solar exposure (MJ/m^2)	*Apodasmia brownii*	28	14.36	±	0.16	12.5	16.1	c
	Austrostipa stipoides	50	15.01	±	0.08	13.6	16.7	ab
	Disphyma crassifolium	33	15.02	±	0.07	14.1	15.7	ab
	Gahnia filum	54	14.83	±	0.10	13.6	16.4	abc
	Hemichroa pentandra	33	15.24	±	0.14	13.6	16.5	a
	Juncus kraussii	163	14.52	±	0.06	12.5	16.4	c
	Samolus repens	108	14.73	±	0.07	13.6	16.5	bc
	Sarcocornia blackiana	22	15.17	±	0.11	14.3	16.7	ab
	Sarcocornia quinqueflora	272	14.97	±	0.04	13.6	16.7	ab
	Selliera radicans	70	14.74	±	0.10	12.5	16.3	abc
	Suaeda australis	26	14.83	±	0.12	13.6	16.0	abc
	Tecticornia arbuscula	57	15.13	±	0.09	13.6	16.5	ab
Mean lowest daily solar exposure (MJ/m^2)	*Apodasmia brownii*	28	12.43	±	0.17	11.0	14.5	c
	Austrostipa stipoides	50	13.12	±	0.07	12.3	14.5	ab
	Disphyma crassifolium	33	13.13	±	0.04	12.9	14.1	ab
	Gahnia filum	54	12.96	±	0.07	12.0	14.5	abc
	Hemichroa pentandra	33	13.43	±	0.12	12.4	14.6	a
	Juncus kraussii	163	12.71	±	0.06	11.0	14.5	bc
	Samolus repens	108	12.94	±	0.07	11.4	14.6	bc
	Sarcocornia blackiana	22	13.20	±	0.05	13.0	14.1	ab
	Sarcocornia quinqueflora	272	13.13	±	0.04	11.4	14.6	ab
	Selliera radicans	70	12.91	±	0.10	11.0	14.6	bc
	Suaeda australis	26	12.98	±	0.08	12.4	14.1	abc
	Tecticornia arbuscula	57	13.35	±	0.08	12.4	14.6	a

Mean annual rainfall (4 levels of difference): *A. brownii* and *S. radicans* displayed similar means (Tukey group **a**); species *J. kraussii, S. repens* and *S. radicans* were not different in terms of means (group **b**); plant species *A. stipoides, G. filum, H. pentandra, S, quinqueflora,*

S. australis and *T. arbuscula* were not significantly different and form group **c**, while all species, except for *A. stipoides, J. kraussii, S. repens, S. quinqueflora* and *S. radicans* exhibited similarity (group **d**).

Mean annual rainfall values were varied approximately two-fold, *D. crassifolium* (581 ± 21) tolerating the driest conditions to *A. brownii* (1099 ± 69) enduring the wettest locations, followed by *J. kraussii* (883 ± 24), which also tolerated the greatest rainfall range (492-2143, 1651), with *S. radicans* (485-2143, 1658). *D. crassifolium* and *S. blackiana* tolerate the lowest rainfall range (485-1073, 588). Congenor species, *S. blackiana* and *S. quinqueflora* exhibited means of 606 ± 33 and 743 ± 12 respectively, however, the rainfall range of *S. quinqueflora* exceeded that of *S. blackiana* by 50% (1543 to 1073 respectively).

Highest annual rainfall (3 levels of difference): plant species *A. brownii* and *S. radicans* displayed commonality (group **a**); species *J. kraussii, S. repens* and *S. radicans* had similar means (Tukey group **b**), and all species, except for *A. brownii, J. kraussii, S. repens* and *S. radicans,* were not significantly different to each other (group **c**).

Tolerance of higher rainfall (highest annual recorded) varied 0.5-fold, with *A. brownii* enjoying the wettest conditions (1456 ± 80) to *D. crassifolium* favouring drier situations (971 ± 41). Similar to mean rainfall, both *J. kraussii* and *S. radicans* tolerated the greatest range (~1800), while congenors *S. blackiana* and *S. quinqueflora* experienced similar means (1010 ± 55, 1104 ± 15 respectively), yet, although each had the same range minimum (735), *S. quinqueflora* tolerated a higher maximum (2024) compared to *S. blackiana* (1504).

Lowest annual rainfall (4 levels of difference): is somewhat a replicate of mean annual rainfall except for group c which became group **d**, and *A. stipoides, G. filum, S. blackiana, S. australis* and *T. arbuscula* made up group **c**.

Similarities for lowest annual rainfall recorded follow that of mean annual rainfall where means values varied two-fold, *A. brownii* (758 ± 56) to *D. crassifolium* (319 ± 17). Again, the greatest range was experienced by *J. kraussii* and *S. radicans* (256-1449, 1193), while the lowest range falls to *S. australis* (273-768, 495). Once more *S. blackiana* and *S. quinqueflora* means varied two-fold (324 to 461); each displaying a similar range

minimum (247mm), however *S. quinqueflora* enjoyed a range maximum of 1196 (spread 949) compared to that of *S. blackiana* of 789 (spread 542).

Mean annual maximum temperature (4 levels of difference): *A. stipoides, D. crassifolium, H. pentandra, S. blackiana* and *T. arbuscula* all shared comparable means (group **a**); all species, except for *A. brownii, D. crassifolium, J. kraussii* and *S. radicans* were not significantly different (group **b**); species *J. kraussii, S. repens, S. radicans* and *S. australis* had similar means (group **d**), while plant species *A. brownii, J. kraussii* and *S. radicans* were common in terms of means (Tukey group **c**).

Annual maximum temperature means varied 16.44 ± 0.18 (*A. brownii*) to 17.76 ± 0.13 (*D. crassifolium*). *S. radicans* tolerated the largest range (13.9-18.1), followed by *A. brownii* (13.9-17.9). *S. quinqueflora* experienced a cooler range minimum (14.9) compared to *S. blackiana*, however both had similar range maximums (18.5).

Mean annual minimum temperature (3 levels of difference): plant species *H. pentandra, S. repens, S. quinqueflora, S. radicans, S. australis* and *T. arbuscula* displayed no significant difference to each other (Tukey group **a**); all species, except for *A. brownii, G. filum, H. pentandra* and *J. kraussii* showed similarity (group **b**), whereas all plant species, except for *H. pentandra, S. repens, S. quinqueflora, S. radicans* and *T. arbuscula* were also similar to each other (group **c**).

Mean values of annual minimum temperatures differed 7.82 ± 0.24 (*A. brownii*) to 9.26 ± 0.22 (*H. pentandra*). The greatest range is experienced by *S. repens* and *S. quinqueflora* (6.2-11.6, 5.4), whereas the least range was tolerated by *D. crassifolium* (7.8-9.8, 2.0). Although *S. blackiana* showed tolerance for a cooler mean (8.30 ± 0.19) to that of *S. quinqueflora* (8.62 ± 0.08), its range was far more limited (7.1-10.5, 3.4) to that of its congenor (6.2-11.6, 5.4).

Highest annual maximum temperature (5 levels of difference): plant species *A. stipoides, D. crassifolium, S. blackiana* and *T. arbuscula* formed group **a**; species *A. stipoides, G. filum, H. pentandra, S, blackiana, S. quinqueflora, S. australis* and *T. arbuscula* displayed similar means (Tukey group **b**); *G. filum, H. pentandra, S. repens* and *S. australis* had common means (group **c**); *H. pentandra, J. kraussii, S. repens, S. radicans* and

S. australis displayed similarity in terms of means (group **d**), and *J. kraussii, S. repens* and *S. radicans* formed the final group (**e**).

The means for highest annual maximum temperature recorded ranged 17.45 ± 0.16 (*A. brownii*) to 18.82 ± 0.05 (*D. crassifolium*). The greatest range (15.1-18.9, 3.8) was tolerated by three species, *A. brownii, J. kraussii* and *S. radicans*, while the smallest range was experienced by *T. arbuscula* (17.4-18.9, 1.5), followed by *G. filum* (17.2-18.9, 1.7). Of the congenor species, *S. quinqueflora* tolerated a slightly cooler mean temperature (18.21 ± 0.04) to that of *S. blackiana* (18.59 ± 0.11), however, both experienced a maximum of 19.2, yet the minimum (17.3) of *S. blackiana* was higher compared to that of *S. quinqueflora* (16.3).

Lowest annual minimum temperature (3 levels of difference): six species, *H. pentandra, S. repens, S. quinqueflora, S. radicans, S. australis* and *T. arbuscula* displayed similar means (Tukey group **a**); all species, except for *A. brownii, D. crassifolium, G. filum, H. pentandra* and *J. kraussii* were similar in terms of means (group **b**), while all species, except for *H. pentandra, S. repens, S. quinqueflora, S. radicans* and *T. arbuscula* exhibited similarity in terms of means (group **c**).

The means of the lowest annual minimum temperature ranged 6.85 ± 0.25 (*A. brownii*) to 8.38 ± 0.24 (*H. pentandra*). The smallest range was experienced by *D. crassifolium* (6.3-8.9^{o}C, 2.6^{o}C), while the greatest range was tolerated by *S. quinqueflora* (5.0-10.8, 5.8) with *A. brownii, A. stipoides, G. filum, J. kraussii* and *S. radicans* following, all experienced the same range (5.0-9.9, 4.9). *S. blackiana* had small range (6.2-9.7, 3.5), with a mean (7.17 ± 0.23) slightly cooler that its congenor species (7.66 ± 0.09).

Mean highest daily solar exposure (3 levels of difference): all species, except for *A. brownii, J. kraussii* and *S. repens,* exhibited commonality in terms of means (group **a**); all plant species, except for *A. brownii, H. pentandra* and *J. kraussii* were not different (Tukey group **b**), while *A. brownii, G. filum, J. kraussii, S. repens, S. radicans* and *S. australis* had similar means (group **c**).

Variation in means for highest daily solar exposure was small, ranging 14.36 ± 0.16 (*A. brownii*) to 15.24 ± 0.14 (*H. pentandra*). Congenor species, *S. blackiana* and *S. quinqueflora* displayed little difference in means (15.17 ± 0.11 and 14.97 ± 0.04

respectively), their range of tolerance being greater with *S. quinqueflora* (13.6-16.7, 3.1) exceeding that of *S. blackiana* (14.3-16.7, 2.4). Species exhibiting the greatest solar exposure range was *J. kraussii* (12.5-16.4, 3.9) differing greater than two-fold to that of *D. crassifolium* (14.1-15.7, 1.6).

Mean lowest daily solar exposure (3 levels of difference): all species, except for *A. brownii, J. kraussii, S. repens* and *S. radicans* exhibited similarity in terms of means (group **a**); all plant species, except for *A. brownii, H. pentandra* and *T. arbuscula* were not different (group **b**), while *A. brownii, G. filum, J. kraussii, S. repens, S. radicans* and *S. australis* had common means (Tukey group **c**).

Like highest daily solar exposure, variation in means for lowest daily solar exposure involve identical species, with *A. brownii* exhibiting 12.43 ± 0.17, while *H. pentandra* exhibited a mean of 13.43 ± 0.12. *S. blackiana* (13.20 ± 0.05) and *S. quinqueflora* (13.13 ± 0.04) displayed similar means, yet the range of *S. quinqueflora* (11.4-14.6, 3.2) was three-fold greater than that of *S. blackiana* (13.0-14.1, 1.1).

Summary – plant species and climate variables

Several climate variables indicated that some plant species were significantly different to other species within that variable. For example, in mean annual rainfall and mean annual maximum temperature, *D. crassifolium, S. blackiana* and *A. brownii* were significantly different to other plants, to the extent that *D. crassifolium and S. blackiana* preferred a dry (581/606mm rainfall) and a warmer climate (17.76/17.61^{o}C mean maximum, and 8.23/8.30^{o}C mean minimum temperature), whereas, *A. brownii* favoured a wetter (1099mm rainfall) and a cooler climate (16.44^{o}C mean maximum, and 7.82^{o}C mean minimum temperature). Conversely, in highest mean daily solar exposure, differences were limited to three clusters, where *A. brownii* and *J. kraussii* formed one cluster (mean 14.36 and 14.52MJ/m^2 respectively), *S. blackiana* and *T. arbuscula* formed the next cluster (mean 15.17 and 15.13MJ/m^2 respectively), while the remaining species loosely made up the final cluster (means ranging 14.73 to 15.02MJ/m^2).

Summary – plant species, edaphic factors and climate variables

The individual Tukey HSD tests on edaphic factors and climate variables also emphasise another important point. One of the seven edaphic factors, O layer depth, had five levels of difference, two factors, LOI550 and EC, displayed four levels of

difference, the remainder displaying three levels of difference. Of the nine climate variables, one, highest annual maximum temperature, displayed five levels, three variables, mean annual rainfall, lowest annual rainfall and mean annual maximum temperature, displayed four levels of difference, while the remainder displayed just three levels of difference. This highlights the value of both edaphic factors and climate variables (in combination), principally LOI550 and EC, and highest annual maximum temperature, mean annual rainfall, lowest annual rainfall and mean annual maximum temperature, in distinguishing differences between plant species.

6.4.3 nMDS ordination

Plant species and nMDS vectors

Species vectors of the 12 selected plant species are presented in Table 6.9. All 12 species were significantly associated with the ordination.

Table 6.9: Plant species and nMDS1 and nMDS2 vector values, ranked by r^2. The hashed line defines various levels of influence in the ordination.

Plant species	MDS1	MDS2	r^2	p-value	
Sarcocornia quinqueflora	0.85992	-0.51044	0.8062	0.001	***
Juncus kraussii	-0.84002	-0.54256	0.7462	0.001	***
Tecticornia arbuscula	0.61627	0.78754	0.2595	0.001	***
Disphyma crassifolium	0.49529	0.86873	0.1620	0.001	***
Apodasmia brownii	-0.94143	0.33721	0.1495	0.001	***
Austrostipa stipoides	-0.23531	0.97192	0.1488	0.001	***
Sarcocornia blackiana	0.35787	0.93377	0.1430	0.001	***
Gahnia filum	-0.42458	0.90539	0.1049	0.001	***
Selliera radicans	-0.79436	0.60745	0.0939	0.001	***
Samolus repens	-0.26923	0.96308	0.0768	0.001	***
Hemichroa pentandra	0.51130	0.85940	0.0373	0.001	***
Suaeda australis	0.27915	0.96025	0.0267	0.004	**

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Two species, *S. quinqueflora* (correlated at 90% – the square root of the r^2 value) and *J. kraussii* (correlated at 86%), stand out as being highly influential in the fit of the selected plant species on the plot-based ordination. The high influence of these two species was a result out of both being individual vegetation communities (ASQ and AJK – see Chapter 3) and being heavily present, individually and jointly, in most of the remaining six vegetation communities. Several other species, *T. arbuscula, D. crassifolium, A. brownii, A. stipoides* and *S. blackiana* had a lesser influence (approximately correlated at

40-50%) in the ordination, while the remaining species had the least influence (correlated at <26%). It is noted that although some species appeared to be of least importance in the structure of this ordination, it did not diminish their value in saltmarsh vegetation communities or associations with other species.

Climate variables and nMDS vectors

Climate variable vectors are tabled in Table 6.10.

Table 6.10: Climate variables and nMDS1 and nMDS2 vector values, ranked by r^2. The hashed line defines levels of influence in the ordination.

Climate variable	MDS1	MDS2	r^2	p-value	
Mean annual maximum temperature	0.98143	0.19182	0.1962	0.001	***
Lowest annual rainfall recording	-0.94569	-0.32507	0.1783	0.001	***
Mean annual rainfall	-0.97031	-0.24185	0.1723	0.001	***
Highest maximum annual temperature	0.95823	0.28601	0.1633	0.001	***
Mean lowest daily solar exposure	0.96840	0.24939	0.1374	0.001	***
Highest annual rainfall recording	-0.98256	-0.18594	0.1203	0.001	***
Mean highest daily solar exposure	0.97081	0.23986	0.1179	0.001	***
Mean annual minimum temperature	0.85265	0.52249	0.0508	0.001	***
Lowest minimum annual temperature	0.84844	0.52929	0.0395	0.002	**

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

No variable was highly influential (being correlated by greater than 50%) in the fit of climate variables to the ordination. Four variables, mean annual maximum temperature, lowest annual rainfall recorded, mean annual rainfall and highest annual maximum temperature displayed influence between 16 and 20%. Mean lowest daily solar exposure, highest annual rainfall recorded and mean highest daily solar exposure displayed influence between 12 and 14%, while the remaining climate variables had the least influence (<5%). Again, it is noted that although some variables appeared to be of least importance in the fit of climate variables to this nMDS ordination, it did not diminish their usefulness in determining the impact of climate to saltmarsh vegetation presence or absence, nor the structure of vegetation communities.

Edaphic factors nMDS vectors

Edaphic factor vectors are tabled in Table 6.11.

Table 6.11: Edaphic factors and nMDS1 and nMDS2 vector values, ranked by r^2. The hashed line defines levels of influence in the ordination.

Edaphic factor	MDS1	MDS2	r^2	p-value	
Roots	-0.85336	-0.52133	0.1580	0.001	***
Loamy-soil	-0.74537	0.66665	0.1562	0.001	***
EC	0.79952	-0.60064	0.1320	0.001	***
Salinity	0.77211	-0.63549	0.1138	0.001	***
Peat	0.70636	-0.70785	0.0805	0.001	***
LOI550	-0.55692	-0.83056	0.0753	0.001	***
LOI850	-0.45781	-0.88905	0.0673	0.001	***
pH	0.54682	0.83725	0.0574	0.001	***
Moisture by weight	-0.37674	-0.92632	0.0526	0.001	***
Bulk density	0.42831	0.90363	0.0394	0.001	***
Moisture by volume	-0.31225	-0.95000	0.0326	0.003	**
Sand	0.98860	0.15055	0.0191	0.018	*
Clay	0.70085	-0.71331	0.0168	0.037	*
Shell	-0.36314	0.93173	0.0117	0.074	.
Bare ground	0.53025	0.84784	0.0101	0.133	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' .05 .' 0.1 ' ' 1.

Similar to climate variables, no edaphic factor was highly influential (being correlated by greater than 50%) in the fit of edaphic factors to the ordination. Four factors, roots, loamy-soil, EC and salinity displayed influence between 33 and 40%. Five factors, peat, LOI550, LOI850, pH and moisture by weight, exhibited influence between 22 and 33%, while two factors, bulk density and moisture by volume, showed decreasing influence (18-20%). The remaining edaphic factors had the least influence (<15%), all with an increasing p-value (>0.01). In this case, the very minor level of influence (r^2<0.02, or 14%) displayed by these factors (sand, clay, shell and bare ground) suggests that they were scattered across all sites and not connected to any community.

nMDS ordination fitted with features

A plot-based nMDS ordination fitted with plant species, climate variable and edaphic factors is presented in Figure 6.33.

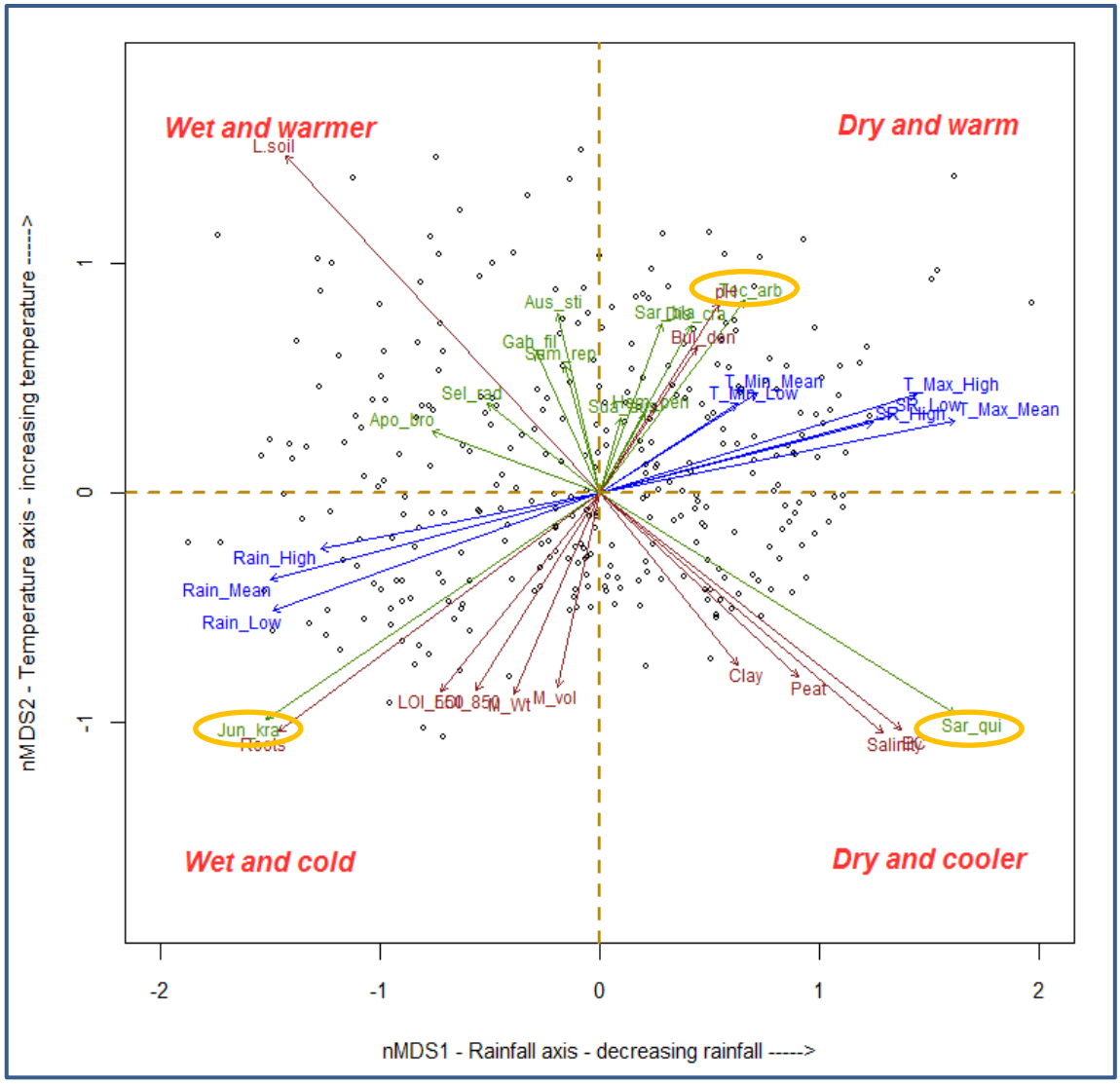

Figure 6.33: A plot-based nMDS ordination fitted with plant species at p<0.005 (**green**), climate variables at p<0.005 (**blue**) and edaphic factors at p<0.005 (**brown**). Plant species circled (**orange**) are top right *T. arbuscula* (Tec_arb), bottom left *J. kraussii* (Jun_kra), and bottom right *S. quinqueflora* (Sar_qui). The ordination has been split to four sectors, these determined and named by a combination of rainfall and temperature variables.

The ordination fitted with plant species, climate variables and edaphic factors clearly demonstrates the relationship between species and soil and climate attributes, as well as plant species association, either individually or jointly.

Climate variables

All rainfall variables were entirely separated from temperature and solar exposure, indicating that decreasing temperature and solar exposure were a response to increasing

rainfall. Conversely, increasing solar exposure was a response to increasing temperature, which leads to decreased cloud cover, and in turn decreasing rainfall.

Climate and plant species

Reference herein is made to vegetation communities, these defined in Chapter 3.

Both *J. kraussii* and *S. quinqueflora* were only separated by rainfall (nMDS 1), temperature (nMDS 2) had no impact on their position in the ordination as both were constrained horizontally on the rainfall axis. Individually, both species formed single species vegetation communities (ASQ – *S. quinqueflora*, and AJK – *J. kraussii)*, this primarily determined by rainfall. The remaining 10 species were separated from *J. kraussii* and *S. quinqueflora* by temperature, and they in turn were split by rainfall, although not to the extent that *J. kraussii* and *S. quinqueflora* had been separated. The close-fitting group of species, *D. crassifolium, S. blackiana* and *T. arbuscula* in the dry and warm sector, formed an association as a vegetation community (ASH – shrubs and herbs) as do *D. crassifolium, H. pentandra, S. blackiana* and *S. australis* to create another community (AHM – mixed herbs). In the wet and warmer sector, *A. stipoides* and *G. filum* formed an association (AGH – graminoids and herbs), often with *S. repens* and other species found in AHM. In some cases, species did cross the theoretical sector boundaries. For example, *A. brownii* and *S. radicans* were found with *J. kraussii*, this association determined by temperature, where *A. brownii* and *S. radicans* preferred a warmer regime than does *J. kraussii*. Therefore, in sites that were not too cold though still wet, the three species will form a rush and herb community (ARH – rushes and herbs). Similarly, *D. crassifolium, H. pentandra, S. blackiana*, species that preferred a dry and warm regime, were found with *A. stipoides* and *G. filum* (species preferring a wet and warm regime) to create a graminoid and herb community (AGH) in the right temperature conditions. Thus, individual plant species were not constrained within a particular climatic region, they can, and often did, form associations with species from neighbouring sectors.

Edaphic factors

Edaphic factors were equally evident in each of the four climatic sectors. Generally, many factors showed a strong response to another. For example, bulk density increased as moisture fell, loamy-soil rose as peat and salinity decreased, all expected outcomes. Interesting outcomes were also noted; pH decreased as LOI rose, possibly as a result of organic matter being more acidic, and pH responded positively to bulk density, this

principally due to heavier soil matter such as sand and shell, being more alkaline. Thus, similar to climate variables, edaphic factors responded in ways as one would have anticipated.

Edaphic factors and plant species

Similar to climate variables and plant species, the predominant outcome in the ordination in respect of plants and edaphic factors was the relationship between *J. kraussii* and *S. quinqueflora*. Here, *J. kraussii* had a strong association with root composition and a negative association with bulk density and pH, while *S. quinqueflora* had an equally strong association with peat, salinity and EC and a negative association with loamy-soil. Similarly, *D. crassifolium, S. blackiana* and *T. arbuscula* displayed strong positive associations with bulk density and pH, whereas the three species had negative associations with LOI and moisture. As noted above with climate variables, plant species were not totally restricted to individual (or combinations of) edaphic factors. Species, *A. brownii* and *S. radicans* both displayed tolerance to loamy-soil, they also had an association with *J. kraussii*, therefore tolerate conditions where root composition was a high soil component. Yet it was less likely that *J. kraussii* would be found where there was a high component of loamy-soil. Again, this was true for *A stipoides, G. filum, D. crassifolium, H. pentandra, S. blackiana* and *S. australis* in relation to loamy-soils, though this was less apparent in the field. In another situation *S. quinqueflora* had a relatively strong association with *D. crassifolium, S. blackiana* in AHM and even *T. arbuscula* in ASH. However, this species was far more tolerant of various conditions than that appeared to be recognised by the ordination. Although the ordination shows the strong association between *S. quinqueflora* and peat, *S. quinqueflora* did grow in loamy-soil and other soils with a higher bulk density.

In the case of the ordination, plant species appear to have been exhibited in their "climax" edaphic environment, the mean of each edaphic factor which, on reflection and evidence in the field, is acceptable for some species, for example *S. blackiana* and *H. pentandra*. What the ordination does not show is the pioneer/colonising position nor the extent of the range of several edaphic factors that several species successfully thrive and survive. For example, *J. kraussii* has been found successfully colonising and growing prolifically in tailings from an old copper mine (Figure 6.34) – the tailings now form a reedy saltmarsh at the mouth of the King River in Macquarie Harbour (central west

coast of Tasmania) (personal observations). A return visit to the site six months later found the advancing front had extended 10 to 15 metres seawards. In a similar case, *S. quinqueflora* has been discovered colonising bare sand (Figure 6.35) at the mouth of the Little Musselroe River near Bridport (central north coast of Tasmania) (personal observations). This location was visited five months previously by the author as part of a coastal saltmarsh survey and *S. quinqueflora* was not recorded here. It is possible that through time, plants themselves modify soil conditions to such an extent that at the climax stage conditions are right for continued successful propagation. Individual species then out-compete to the exclusion of others to become mono-specific such as *Sarcocornia* "lawns" (ASQ) or *Juncus* rushland (AJK).

Figure 6.34: *Juncus kraussii* colonising copper tailings at the mouth of the King River, Macquarie Harbour. This site was visited six months after the adjacent photo was taken, and *J. kraussii* had propagated another 10-15 metres to the right demonstrating its highly adaptable capacity as a colonising species.

Figure 6.35: *Sarcocornia quinqueflora* colonising bare sand at the mouth of the Little Musselroe River (Bridport). Site was visited five months prior adjacent photo, and no *S. quinqueflora* was evident at this site. This demonstrates the highly adaptable capacity of *S. quinqueflora* as a colonising species. **Photo:** V Prahalad.

6.4.4 Plant species suitability

It is difficult to individualise plant species based on either edaphic factors alone or on climate variables alone. It has become apparent that any review should be based on a combination of both attributes. Collectively, they play an important role in species presence (and/or absence) in coastal saltmarshes, and the use of individual edaphic or climate attributes could lead to plant selection errors. This is supported by Fariña *et al.* (2018) where they report that variation (which includes individual species presence/ absence) is explained by various attributes, including precipitation, temperature and soil salinity.

Therefore, which factors/variables should be considered when selecting the most appropriate plant species to be used? Attributes that vary little or not at all between species can be down-weighted as they provide less information on individual species habitat preference. Additionally, consideration should also be given to the ease and costs of analysing edaphic factors, as some, for example LOI550 and LOI850 are costly in time and financially. Simple analysis, such as organic layer depth (a straightforward measurement in the field) and moisture (an uncomplicated laboratory measurement with a reliable set of weighing scales) are relatively fail-proof and are very cost effective. Reliable climate data is readily available from Bureau of Meteorology websites and is cost free!

To help identify key attributes, two outputs from the statistical analysis are useful – ANOVA and the Tukey post hoc tests with similarity/dissimilarity terms applied.

ANOVA and Tukey groups

The two ANOVA outputs and Tukey groups tables (Tables 6.3, 6.5, 6.6 and 6.8) were combined, this to enable identification of key attributes that contain plant species highly significantly different to other plant species within each factor/variable (Table 6.12).

Table 6.12: Combined ANOVA outputs and Tukey group tables of all edaphic and climate attributes (ranked by descending F value). Selected attributes in **green**. Those highlighted in **blue** are useful if required to remove any ambiguity (see text).

Edaphic and climate attributes	F value	p-value		Tukey groups
Lowest annual rainfall (mm)	**16.760**	**<2e-16**	***	**4**
Mean annual rainfall (mm)	**15.750**	**<2e-16**	***	**4**
Mean annual maximum temperature (°C)	**14.180**	**<2e-16**	***	**3**
Highest maximum annual temperature (°C)	**12.800**	**<2e-16**	***	**5**
Moisture by volume (%)	**10.100**	**<2e-16**	***	**3**
Highest annual rainfall (mm)	9.858	<2e-16	***	3
Organic layer depth (cm)	**9.187**	**9.76e-16**	***	**5**
EC (dS/m)	**9.185**	**9.85e-16**	***	**4**
Mean lowest daily solar exposure (MJ/m^2)	9.038	1.91e-15	***	3
Mean highest daily solar exposure (MJ/m^2)	7.733	6.93e-13	***	3
Bulk density (g cm^2)	7.073	1.36e-11	***	3
Mean annual minimum temperature (°C)	6.415	2.59e-10	***	3
LOI550 (%)	**6.272**	**4.90e-10**	***	**4**
Lowest minimum annual temperature (°C)	6.250	5.26e-10	***	3
pH	5.884	2.76e-09	***	3
LOI850C (%)	5.434	2.02e-08	***	3

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Six key attributes were selected based on lowest p-value, highest F value and greatest number of levels of difference (Tukey groups). The attributes are made up from climate variables: lowest annual rainfall, mean annual rainfall, and highest maximum annual temperature; and edaphic factors: organic layer depth, moisture by volume and EC. It is noted that moisture (by volume) rated poorly in terms of levels of difference (Tukey groups), however it was included as it exhibited a high F value (hence a low p-value), and it is less costly and time consuming to measure than LOI550. These attributes were considered the best options to use in selection of suitable plant species for restoration purposes. To confirm selection of individual species to a more unambiguous level, two other attributes, mean annual maximum temperature and LOI550 can be used if required.

Suitable plant species

Three plant species – *J. kraussii, S. repens* and *S. quinqueflora* – have been identified as being suitable for initial plantings in Tasmanian coastal restoration sites (Figures 6.36 to 6.38). These species were the most abundant throughout the Tasmania, with *S. quinqueflora* present in more than two-thirds (70%) of the plots, *J. kraussii* in almost

half (44%), and *S. repens* recorded in more than one-third (36%) of the plots. Furthermore, each individual species exhibits an extensive range in most edaphic factors, and when climate variables are considered, *S. quinqueflora* prefers a drier, warmer climate, *J. kraussii* a wetter, cooler climate and *S. repens* can reasonably cope in both conditions. However, their suitability is individually linked to a specific range within each edaphic and climatic attribute (Tables 6.13 and 6.14).

Table 6.13: Recommended plant species and key edaphic factor ranges (in order of importance). The ranges represent the interquartile range – the ecological niche or habitable range.

Species	Moisture	O layer	EC	LOI550
Juncus kraussii	60.6 to 84.2	12.0 to 34.0	7.2 to 25.3	16.8 to 48.9
Samolus repens	60.4 to 84.8	10.0 to 31.0	7.9 to 30.2	13.1 to 41.4
Sarcocornia quinqueflora	56.6 to 82.6	10.0 to 25.0	9.7 to 34.3	13.4 to 40.9

Table 6.14: Recommended plant species and key climate variable ranges (in order of importance). The ranges represent the interquartile range – the ecological niche or habitable range.

Species	Lowest annual rainfall	Mean annual rainfall	Highest max annual temp	Mean annual max temp
Juncus kraussii	376 to 654	700 to 979	17.4 to 18.8	16.6 to 17.5
Samolus repens	375 to 648	704 to 987	17.4 to 18.8	16.8 to 17.6
Sarcocornia quinqueflora	330 to 537	593 to 806	17.7 to 18.8	17.0 to 17.6

A method that will enable appropriate selection of a suitable pioneer plant species is described below.

Figure 6.36: *Juncus kraussii* (sea rush).

Left: Field view – Sea Elephant Bay, King Island (courtesy V. Prahalad).

Above: Close-up view of seed head.

Figure 6.37: *Samolus repens* (creeping brookweed).

Left: In flower, King Island (courtesy V. Prahalad).

Above: Close-up view of creeper.

Figure 6.38: *Sarcocornia quinqueflora* (beaded glasswort).

Left: Field view – succulent lawn – Cremorne (Tasmania).

Above: Close-up view of succulent.

Decision tool charts

From results and discussion (above), individual decision-making charts for each of the 12 plant species have been developed to aid the selection of appropriate species useful in restoration work. Decision charts for the three selected species (*J. kraussii, S. repens* and *S. quinqueflora*) as being suitable for restoration work, are presented below (Figures 6.39 to 6.41, see following page); decision-making charts for the remaining nine species are displayed in Appendix 6A.3. All eight edaphic and climatic attributes (see Tables 6.13 and 6.14 above) have been used in the charts in order of significance as identified in the above combined ANOVA and Tukey group tables (see Table 6.12). The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitable range" of the plant species); the value of the 1st quartile is presented at the end point on the left of the median, the value of the 3rd quartile is displayed at the end point on the right of the median. Due to the large disparity of scale in the data range, all attributes were scaled prior to design of the decision charts, thus providing a more informative display. Instructions on use of the decision charts follow the charts.

Notes for use of decision charts

Climate data: collect information as per following. The Bureau of Meteorology has a useful webpage to source climate information, "Climate Data Webpage" – http://www.bom.gov.au/climate/data-services/#tabs=5. Accessing the "Climate averages" tab will take the researcher to "Climate Data Online" – http://www.bom.gov.au/climate/data/index.shtml?bookmark=200 – where, by entering the location (e.g. nearest town) of the proposed restoration site, options of closest BOM weather recording stations will be displayed. It may be necessary to use data from two weather stations as one may only record rainfall and solar exposure, not temperature.

Soil data: at the proposed site record the mean depth of the organic layer from several plots; take soil samples to analyse for EC and take several cores (a set volume) of the top 10cm to analyse for soil moisture. The soil analysis can be completed in a simple home laboratory with a suitable EC/salinity meter and a reliable set of scales.

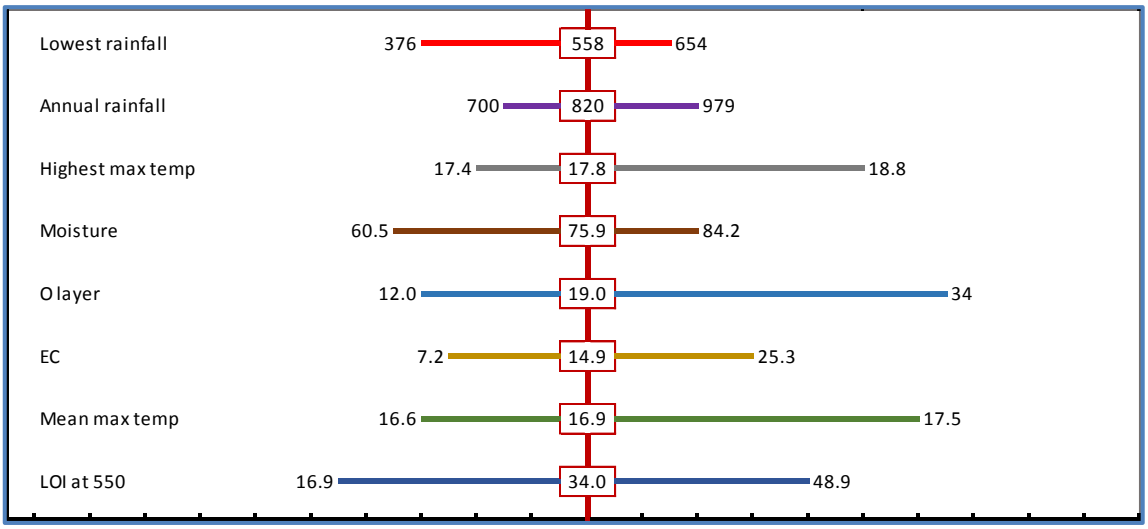

Figure 6.39: *Juncus kraussii* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The 1st quartile is presented on the left, the 3rd quartile is displayed on the right of the median.

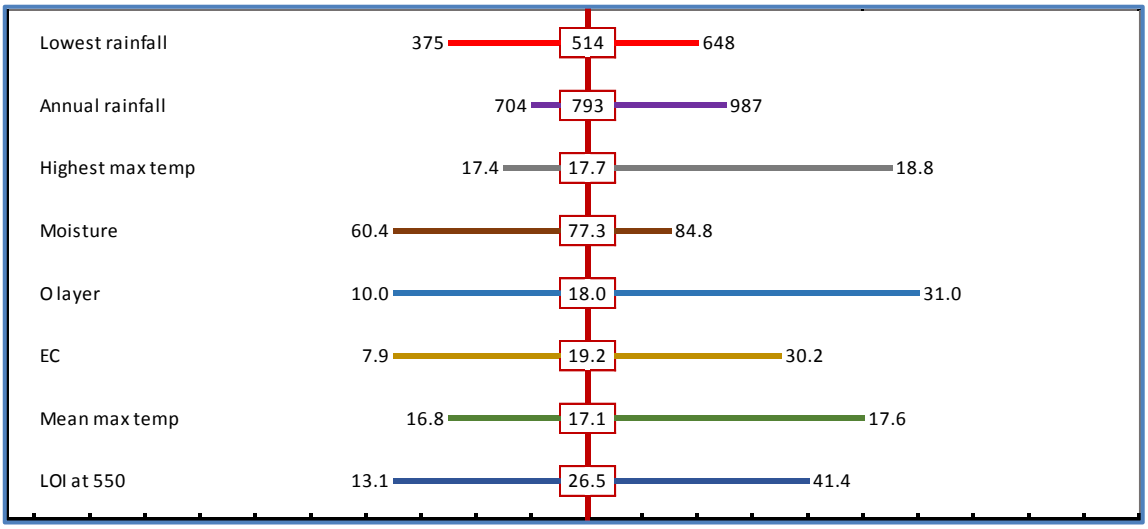

Figure 6.40: *Samolus repens* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The 1st quartile is presented on the left, the 3rd quartile is displayed on the right of the median.

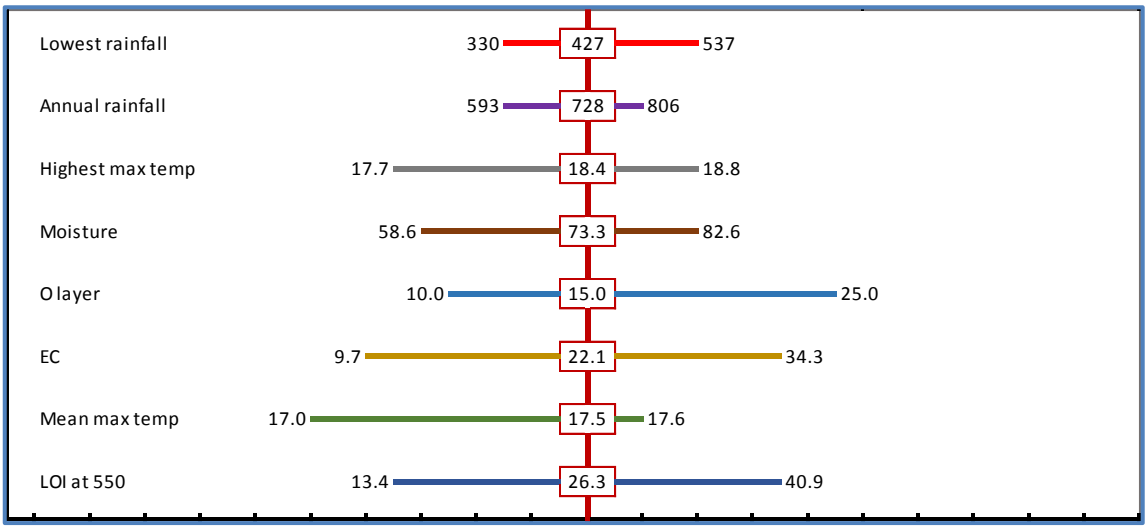

Figure 6.41: *Sarcocornia quinqueflora* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The 1st quartile is presented on the left, the 3rd quartile is displayed on the right of the median.

Decision charts: record the climate and soil data on the *J. kraussii, S. repens* and *S. quinqueflora* charts (the three species represent the best options for selecting plant species). For example, using *J. kraussii* as an option, if the moisture by volume is 67%, mark the point midway between 60.5 (1st quartile value) and 75.9 (the median value); if the moisture by volume is 83%, place a mark to the left of, but close to 84.2 (3rd quartile value). Chart the remaining data in this manner against individual attributes; note that one or more values may be outside the indicated range, however, still mark the individual values. Repeat the climate and soil data on the *S. repens* and *S. quinqueflora* charts. Once completed, review each decision chart as per below.

Decision points:

1. If one chart records all data points within the individual attribute endpoints (that is within the interquartile range), select this as an appropriate species to use;
2. If two charts report a similar result, select the species where most data points are closer to the median especially those of the first six attributes (considered the most significant);
3. If no chart records all data points within the individual attribute endpoints, select one where data points are within the first seven attributes (note: the attributes are in order of significance);
4. If two charts report data points within the first seven attributes, select the one where most data points are closest to the median of those seven attributes;
5. If no chart records data points within the first seven attributes endpoints, select one where data points are within the first six attributes;
6. If two charts report data points within the first six attributes, select the one where most data points are closest to the median of those six attributes.

Once pioneer species have become established in the restoration zone, new site data can be used on the remaining decision charts to determine suitable species for secondary plantings to encourage vegetation diversity within the new saltmarsh. Be aware that the introduced pioneer species may have modified the soil in respect of several edaphic factors and it would be prudent to take new soil samples and analyse as described above.

Demonstration of decision chart use

To demonstrate the value of species decision charts, key climate variables and edaphic factors from three unrelated sites are presented in Table 6.15. These data points have been charted to the three individual species decision charts – *J. kraussii, S. repens* and *S. quinqueflora* – Figures 6.44, 6.45 and 6.46 respectively.

Table 6.15: Examples of data points to determine suitable plant species for a restoration site. The three coloured stars are used to denote data points on each chart, representing each individual site.

Site/ID	Lowest annual rainfall	Mean annual rainfall	Highest max annual temp	Moisture	O layer depth	EC	Mean annual max temp	LOI550
A	520	790	17.8	75.0	15.0	22.8	17.1	23.2
B	570	852	17.5	77.2	21.5	7.2	16.7	37.4
C	350	680	18.4	70.1	14.0	18.0	17.7	28.2

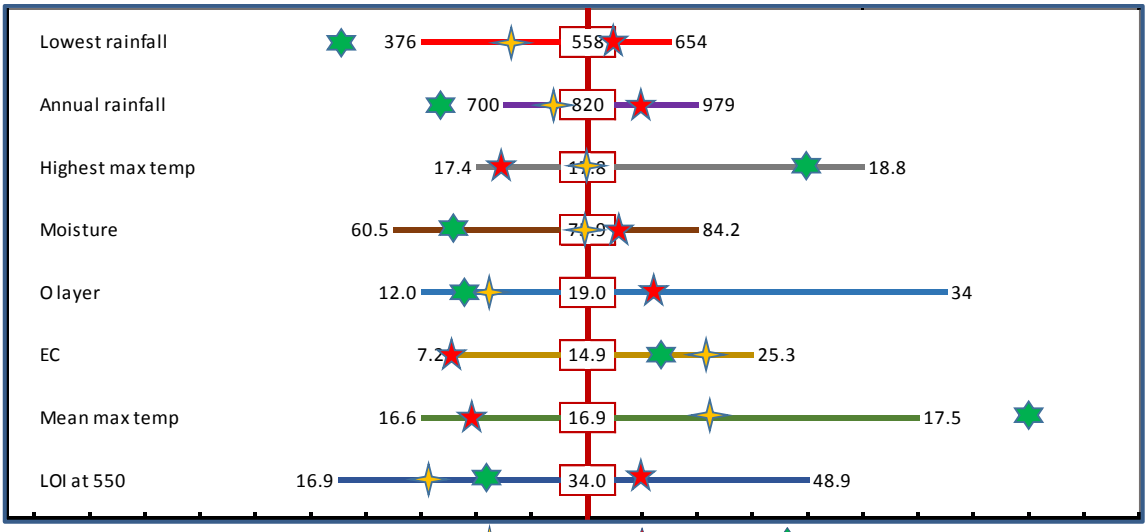

Figure 6.42: *Juncus kraussi* decision chart. = Site A; = Site B; = Site C.

The edaphic and climate attributes are listed by significance; charting data points can be by estimation, subject to care. In this case, Site C (green star) data points, fall outside the range for a number of attributes, particularly in the first two attributes – lowest annual rainfall and mean annual – thereby precluding *J. kraussii* as a suitable plant species. Both Site A (yellow star) and Site B (red star) data points fall well inside many attributes, often close to the median values. It could be argued that Site A is the best fit, however when reviewing the final two attributes – mean maximum temperature and LOI550 – Site B is a better fit, thus suggesting that *J. kaussii* would be a suitable species at Site B.

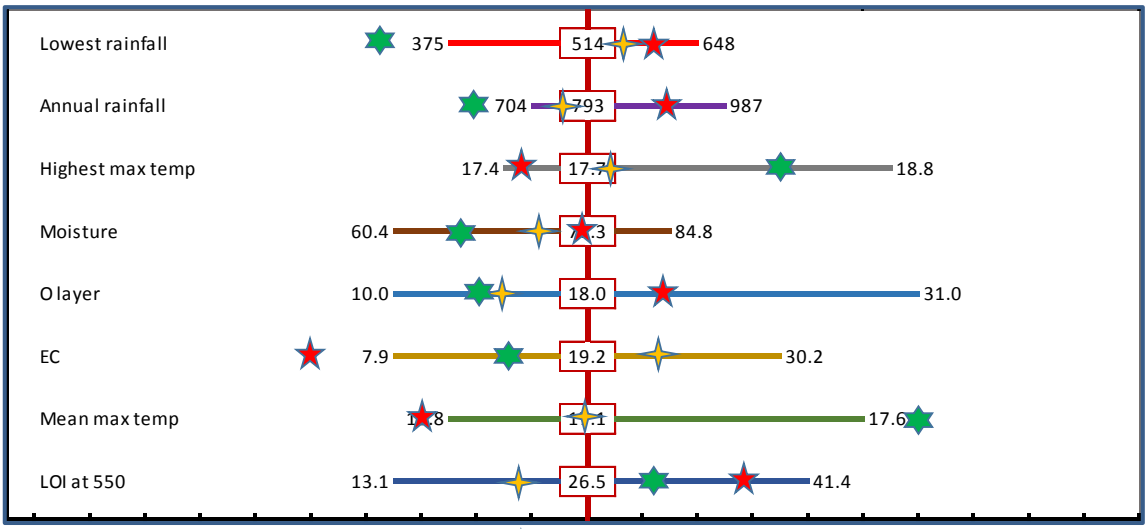

Figure 6.43: *Samolus repens* decision chart. = Site A; = Site B; = Site C.

The edaphic and climate attributes are listed by significance; charting data points can be by estimation, subject to care. In this case, Site B (red star) and Site C (green star) data points fall outside the range for several attributes, particularly for Site C – lowest annual rainfall and mean annual rainfall, indicating that *S. repens* is an unsuitable plant species for Site C. This is also clear for Site B where two attributes – EC and mean annual maximum temperature – are outside the range, though it is noted that these two atributes are lower in the order, thereby attaining a lesser importance. All Site A (yellow star) data points fall inside edaphic and climate attribute ranges, signifying that *S. repens* would be a suitable species at Site A. It is noted that *S. repens* may also be a possible plant species at Site B. However, the two outliers indicated earlier, somewhat preculde this species from being highly suitable at Site B.

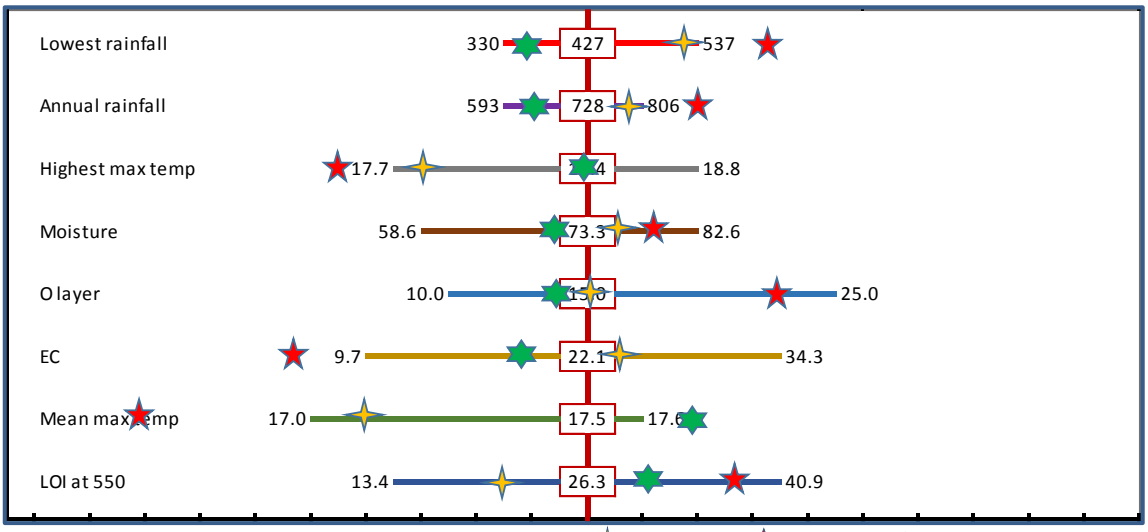

Figure 6.44: *Sarcocornia quinqueflora* decision chart. = Site A; = Site B; = Site C.

The edaphic and climate attributes are listed by significance; charting data points can be by estimation, subject to care. In this case Site B (red star) data points fall outside the range for a number of attributes, particularly highest annual maximum temperature and EC, both being important attributes. All Site C (green star) data points, except for mean annual maximum temperature, are well positioned within the ecological range, in many cases close to the attribute median. This demonstrates that *S. quinqueflora* would be an ideal species at Site C. It is noted that in many cases Site A would also be suiable for *S. quinqueflora*, although Site A recording a lower overall temperature may preclude this species being highly appropriate here.

Plant species suitability by site are presented in Table 6.16.

Table 6.16: Suitability or otherwise of individual plant species to sites described above (Table 6.16).

Site	*Juncus kraussii*	*Samolus repens*	*Sarcocornia quinqueflora*
A	Unsuitable	**Suitable**	Unsuitable
B	**Suitable**	Unsuitable	Unsuitable
C	Unsuitable	Unsuitable	**Suitable**

It is proposed that the decision charts are made available in colour of A4 size for ease of use and laminated to make each reusable. Training in use could be provided through National Resource Management (NRM) groups to local community groups interested in coastal saltmarsh restoration and monitoring. These decision charts are useful in Tasmania only, as Tasmania coastal saltmarsh data has been used to design the charts. However, in future, the charts may be valuable in other areas providing the edaphic and climate attribute ranges have been updated to reflect local conditions. It is assumed that key attributes used in the charts will be identical (or similar) for use in other locations.

6.5 Conclusion

It is difficult to compare results from this study with others that have a similar focus. Many studies on edaphic factors and plant species have an emphasis on salinity and/or pH versus vegetation communities (associations of species), often restricted to a single site, rather than a complete range of abiotic factors including climate variables and individual plant species over several sites. Although many plant species analysed in this study are not restricted to the Tasmanian coastal saltmarsh zone (some are found in south eastern mainland Australia and New Zealand), climate variables are, hence the results presented here are unique to Tasmania. It is understood that comparisons can be made to the significance of certain attributes that have been analysed here (salinity is one that is well documented in other studies), however, this study has clearly demonstrated that a full range of attributes, a range that includes climate data, should be used to determine plant species suitability in saltmarsh restoration projects. Furthermore, most dominant saltmarsh plant species are present over a wide range of edaphic factors and climate variables, thus demonstrating the ability of a species, either individually, or in association with other species, to occupy a wide variety of soil types. This allows for a greater distribution in coastal Tasmanian saltmarshes, in turn adding species richness to many individual locations.

Finally, the study aims were realised – three key plant species were identified, these suitable for restoration sites, along with information on the extent of the range for each individual edaphic factor and climate variable. A workable decision-making tool has been devised, accompanied by a set of instructions and examples on usage.

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6.7 Appendices

6A.1 Edaphic factors and plant species ranges

6A.2 Climate variables and plant species ranges

6A.3 Decision charts

6A.1 Edaphic factors and plant species ranges

Table 6A.1: Minimum, 1st, 2nd and 3rd quartile, and maximum values by plant species (eight of the 12 statistically analysed) by each edaphic factor. The areas shaded light green are the edaphic factor ranges (the inter-quartile range) in which each species is found and is an indication of the "ecological/best fit" for that species within that individual edaphic factor.

Factor	Species >	Apo_bro	Aus_ sti	Dis_cra	Gah_ fil	Hem_pen	Jun_ kra	Sam_ rep	Sar_bla	Sar_ qui	Sel_ rad	Sua_ aus	Tec_ arb
LOI550 (%)	Minimum	1.44	0.81	3.60	3.78	5.92	1.26	1.26	1.19	0.81	2.66	2.32	1.77
	1st quartile	24.74	6.35	13.19	15.84	16.43	16.87	13.13	5.48	13.38	16.12	14.99	12.33
	Median	37.07	16.01	21.36	30.71	32.20	34.01	26.45	17.52	26.34	31.44	24.71	23.29
	3rd quartile	55.65	24.19	31.49	37.38	45.65	48.87	41.40	23.88	40.93	51.84	39.07	34.35
	Maximum	68.77	50.24	55.98	59.24	68.77	78.85	72.56	32.16	68.77	72.56	56.26	55.98
LOI850 (%)	Minimum	1.78	1.17	5.01	4.47	6.58	1.56	1.56	4.37	1.17	4.95	2.69	2.76
	1st quartile	26.53	9.60	17.61	17.61	17.91	19.76	15.16	9.72	15.66	19.16	17.91	15.36
	Median	41.55	18.05	26.29	33.08	34.59	35.98	30.40	20.43	31.39	34.83	28.16	28.65
	3rd quartile	55.31	28.12	33.71	41.33	48.66	52.64	46.66	27.02	45.45	55.20	44.65	39.09
	Maximum	72.79	52.70	57.57	67.32	72.79	80.65	75.82	39.09	72.79	76.55	59.80	62.47
Organic layer depth (cm)	Minimum	7.0	0.0	2.0	5.0	5.0	0.0	2.0	0.0	0.0	2.0	5.0	0.0
	1st quartile	17.0	9.0	7.0	10.0	12.0	12.0	10.0	6.0	10.0	12.0	11.0	10.0
	Median	34.5	11.0	10.0	15.0	15.0	19.0	18.0	10.0	15.0	18.0	15.0	13.0
	3rd quartile	38.0	15.0	12.0	29.0	19.0	34.0	31.0	11.0	25.0	31.0	28.0	20.0
	Maximum	45.0	20.0	18.0	45.0	28.0	45.0	45.0	16.0	42.0	45.0	40.0	35.0

Factor	Species >	Apo_bro	Aus_ sti	Dis_cra	Gah_ fil	Hem_pen	Jun_ kra	Sam_ rep	Sar_bla	Sar_ qui	Sel_ rad	Sua_ aus	Tec_ arb
pH	Minimum	4.66	4.66	4.51	4.99	4.94	4.36	4.75	4.92	4.45	3.86	5.40	5.10
	1st quartile	5.53	6.02	5.11	5.84	5.82	5.59	5.72	5.96	5.77	5.38	6.44	6.23
	Median	5.90	6.46	6.18	6.22	6.13	5.97	6.18	6.28	6.18	5.96	6.68	6.57
	3rd quartile	6.17	7.26	6.63	6.60	6.58	6.43	6.66	6.88	6.67	6.49	7.23	7.09
	Maximum	6.60	8.17	7.77	7.63	7.23	7.63	8.05	8.17	8.00	8.00	7.87	8.15
EC (dS/m)	Minimum	0.48	0.80	1.53	2.27	5.76	0.40	0.40	1.53	0.79	1.16	4.43	4.11
	1st quartile	7.57	3.02	4.58	6.23	21.13	7.23	7.90	4.51	9.66	3.86	9.38	11.97
	Median	16.32	5.41	14.04	17.23	32.11	14.88	19.15	8.76	22.08	11.86	26.82	22.75
	3rd quartile	25.34	12.10	24.66	26.38	44.67	25.25	30.22	20.37	34.28	25.27	34.13	34.13
	Maximum	43.31	25.58	45.10	54.15	56.29	46.37	54.15	26.94	65.90	44.67	55.52	63.77
Moisture (by volume %)	Minimum	53.90	5.54	16.73	35.76	56.14	25.22	30.00	16.73	23.36	18.72	41.27	41.96
	1st quartile	70.99	33.70	47.60	60.55	71.85	60.53	60.42	30.22	58.57	56.55	60.55	64.86
	Median	78.97	58.57	62.88	71.94	81.23	75.90	77.28	55.93	73.34	72.85	74.00	74.17
	3rd quartile	85.25	71.32	68.47	83.17	86.73	84.15	84.76	66.52	82.57	82.59	81.53	81.53
	Maximum	98.50	85.75	94.71	91.89	94.68	98.60	96.00	82.60	98.50	96.00	91.71	91.71
Soil bulk density (g/cm^3)	Minimum	0.10	0.14	0.12	0.12	0.14	0.08	0.08	0.27	0.08	0.11	0.12	0.13
	1st quartile	0.15	0.56	0.40	0.19	0.18	0.17	0.19	0.51	0.19	0.17	0.19	0.23
	Median	0.22	0.67	0.61	0.42	0.20	0.24	0.28	0.68	0.33	0.25	0.31	0.40
	3rd quartile	0.39	0.94	0.77	0.69	0.41	0.55	0.54	0.92	0.64	0.57	0.59	0.63
	Maximum	0.71	1.39	1.03	1.13	0.72	1.13	1.00	1.43	1.23	1.15	1.13	1.02

Species names: Apo_bro = *Apodasmia brownii,* Aus_sti = *Austrostipa stipoides,* Dis_cra = *Disphyma crassifolium,* Gah_fil = *Gahnia filum,* Hem_pen = *Hemichroa pentandra,* Jun_kra = *Juncus kraussii,* Sam_rep = *Samolus repens,* Sar_bla = *Sarcocornia blackiana,* Sar_qui = *Sarcocornia quinqueflora,* Sel_rad = *Selliera radicans,* Sua_aus = *Suaeda australis,* Tec_arb = *Tecticornia arbuscula*.

6A.2 Climate variables and plant species ranges

Table 6A.2: Minimum, 1st, 2nd and 3rd quartile, and maximum values by all plant species by each climate variable. The areas shaded light green are the climate variable ranges (the inter-quartile range) in which each species is found and is an indication of the "ecological/best fit" for that species within that individual climate variable.

Variable	Species >	Apo_bro	Aus_sti	Dis_cra	Gah_fil	Hem_pen	Jun_kra	Sam_rep	Sar_bla	Sar_qui	Sel_rad	Sua-aus	Tec_arb
Mean annual rainfall (mm)	Minimum	636	492	485	492	696	492	492	492	485	485	492	485
	1st quartile	878	561	492	610	696	700	704	492	593	700	561	525
	Median	979	700	593	700	728	820	793	593	728	819	704	696
	3rd quartile	1518	758	593	820	762	979	987	593	806	1073	820	762
	Maximum	2143	987	744	1104	820	1104	1104	718	1104	1543	1104	1104
Highest annual rainfall (mm)	Minimum	952	735	735	735	1030	735	735	735	735	739	735	735
	1st quartile	1171	844	735	947	1043	1039	1049	735	952	1043	947	795
	Median	1284	1148	915	1133	1056	1192	1180	1148	1109	1212	1118	1056
	3rd quartile	1993	1229	1148	1229	1196	1328	1408	1148	1229	1458	1229	1168
	Maximum	2538	1504	1504	1484	1337	1504	1484	1504	1504	2024	1484	1484
Lowest annual rainfall (mm)	Minimum	318	247	247	247	256	256	256	247	247	260	273	247
	1st quartile	549	330	247	330	363	376	375	247	330	376	322	297
	Median	654	338	297	363	395	558	515	297	427	516	395	395
	3rd quartile	1026	452	348	516	512	654	648	338	537	768	579	491
	Maximum	1449	625	435	768	648	847	1026	395	847	1196	768	768

Variable	Species >	Apo_bro	Aus_sti	Dis_cra	Gah_fil	Hem_pen	Jun_kra	Sam_rep	Sar_bla	Sar_qui	Sel_rad	Sua-aus	Tec_arb
Mean annual maximum temperature (°C)	Minimum	16.5	16.2	17.6	16.6	16.8	16.2	16.5	17.5	16.2	16.2	16.8	16.8
	1st quartile	16.5	17.0	17.6	16.8	17.1	16.6	16.8	17.6	17.0	16.6	17.1	17.1
	Median	16.65	17.6	17.6	17.3	17.5	16.9	17.1	17.6	17.5	17.0	17.6	17.6
	3rd quartile	16.95	17.6	17.9	17.6	17.6	17.5	17.6	17.9	17.6	17.5	17.6	17.8
	Maximum	17.6	18.5	17.9	18.1	18.1	18.1	18.1	17.9	18.5	18.1	18.1	18.1
Mean annual minimum temperature (°C)	Minimum	6.2	6.2	7.8	6.2	7.7	6.2	6.2	7.8	6.2	6.2	6.2	7.7
	1st quartile	6.8	7.8	7.8	7.7	8.1	6.8	7.85	7.8	7.8	8.1	7.8	8.1
	Median	7.9	7.9	8.1	7.8	9.0	8.1	8.9	7.9	8.4	8.9	8.1	8.1
	3rd quartile	8.7	9.0	8.1	8.9	10.0	8.9	10	8.1	9.5	10.0	9.0	10.0
	Maximum	10.6	10.6	8.1	10.6	11.6	10.6	11.6	8.1	11.6	10.6	10.5	11.6
Highest annual maximum temperature (°C)	Minimum	16.3	17.2	18.8	17.2	16.3	16.3	16.3	18.8	16.3	15.1	16.3	17.4
	1st quartile	17.3	17.8	18.8	17.4	17.7	17.4	17.4	18.8	17.7	17.3	17.7	17.8
	Median	17.4	18.8	18.8	18.0	17.8	17.8	17.7	18.8	18.4	17.7	18.8	18.8
	3rd quartile	18.0	18.9	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8
	Maximum	18.9	19.2	18.8	18.9	18.9	18.9	18.9	18.8	19.2	18.9	18.9	18.9
Lowest annual minimum temperature (°C)	Minimum	5.0	5.0	6.3	5.0	6.7	5.0	5.0	6.2	5.0	5.0	5.0	6.3
	1st quartile	6.2	6.7	6.3	6.7	7.2	6.2	6.9	6.3	6.7	7.2	6.7	7.2
	Median	6.9	7.0	7.2	6.8	8.0	7.2	8.0	6.9	7.2	8.0	7.2	7.2
	3rd quartile	7.8	8.1	7.2	8.0	9.6	8.1	9.1	7.2	8.6	8.9	8.0	9.2
	Maximum	9.9	9.9	8.5	9.9	10.8	9.9	10.8	8.5	10.8	9.9	9.7	10.8

Variable	Species >	Apo_bro	Aus_sti	Dis_cra	Gah_fil	Hem_pen	Jun_kra	Sam_rep	Sar_bla	Sar_qui	Sel_rad	Sua-aus	Tec_arb
Mean highest daily solar exposure (MJ/m^2)	Minimum	12.5	14.1	14.1	13.6	13.6	12.5	13.6	14.3	13.6	13.6	13.6	14.1
	1st quartile	13.9	14.8	14.8	14.1	14.7	13.9	14.1	14.8	14.5	14.2	14.3	14.8
	Median	14.1	15.0	15.0	15.0	15.3	14.4	14.7	15.2	15.0	14.7	14.8	15.1
	3rd quartile	14.9	15.3	15.4	15.3	16.2	15.1	15.3	15.4	15.4	15.3	15.3	15.5
	Maximum	16.1	16.0	15.7	16.4	16.5	16.4	16.5	16.0	16.7	16.3	16.0	16.5
Mean lowest daily solar exposure (MJ/m^2)	Minimum	11.0	12.3	13.1	12.0	12.4	11.4	11.4	13.1	12.0	11.0	12.4	12.7
	1st quartile	12.0	12.9	13.1	12.6	12.9	12.3	12.4	13.1	12.7	12.4	12.7	13.1
	Median	12.2	13.1	13.1	12.9	13.3	12.6	12.9	13.1	13.1	13.0	13.1	13.1
	3rd quartile	13.0	13.3	13.1	13.2	14.3	13.2	13.4	13.1	13.4	13.4	13.2	13.4
	Maximum	14.5	13.6	13.1	14.0	14.6	14.3	14.6	13.1	14.4	14.6	13.6	13.4

Species names: Apo_bro = *Apodasmia brownii,* Aus_sti = *Austrostipa stipoides,* Dis_cra = *Disphyma crassifolium,* Gah_fil = *Gahnia filum,* Hem_pen = *Hemichroa pentandra,* Jun_kra = *Juncus kraussii,* Sam_rep = *Samolus repens,* Sar_bla = *Sarcocornia blackiana,* Sar_qui = *Sarcocornia quinqueflora,* Sel_rad = *Selliera radicans,* Sua_aus = *Suaeda australis,* Tec_arb = *Tecticornia arbuscula*.

6A.3 Decision charts

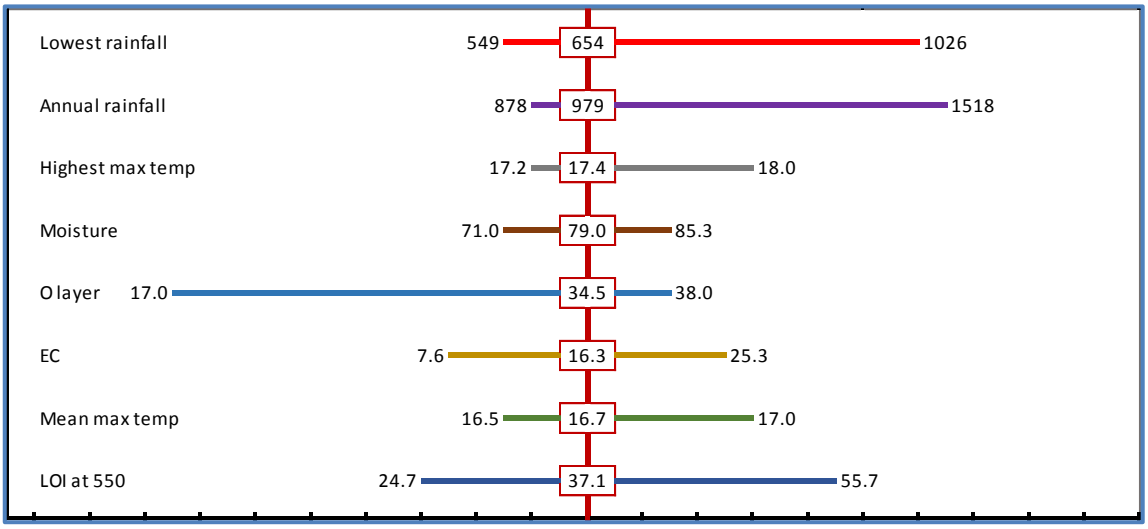


Figure 6A.3.1: *Apodasmia brownii* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

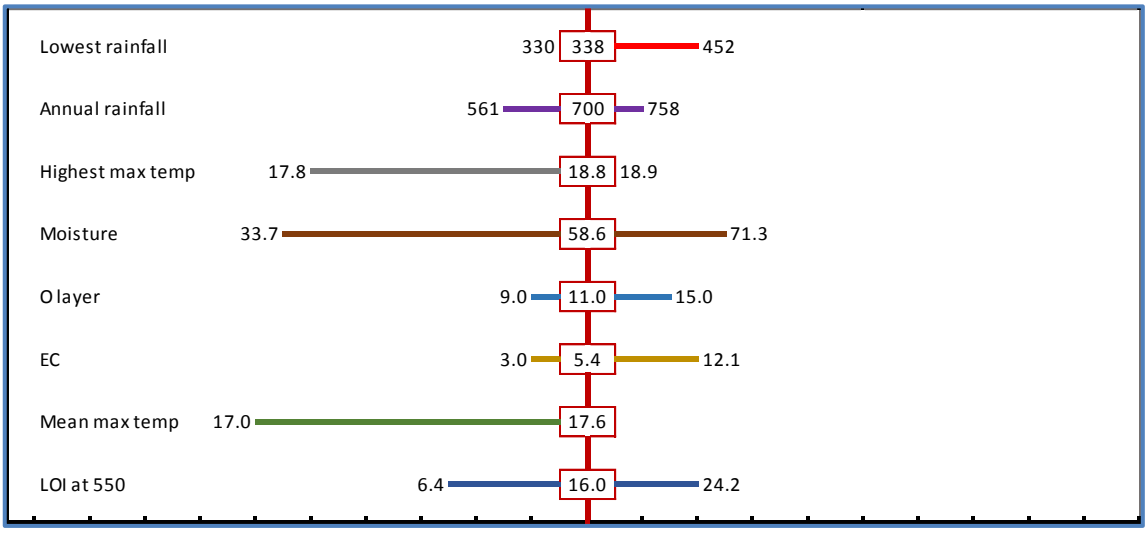


Figure 6A.3.2: *Austrostipa stipoides* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

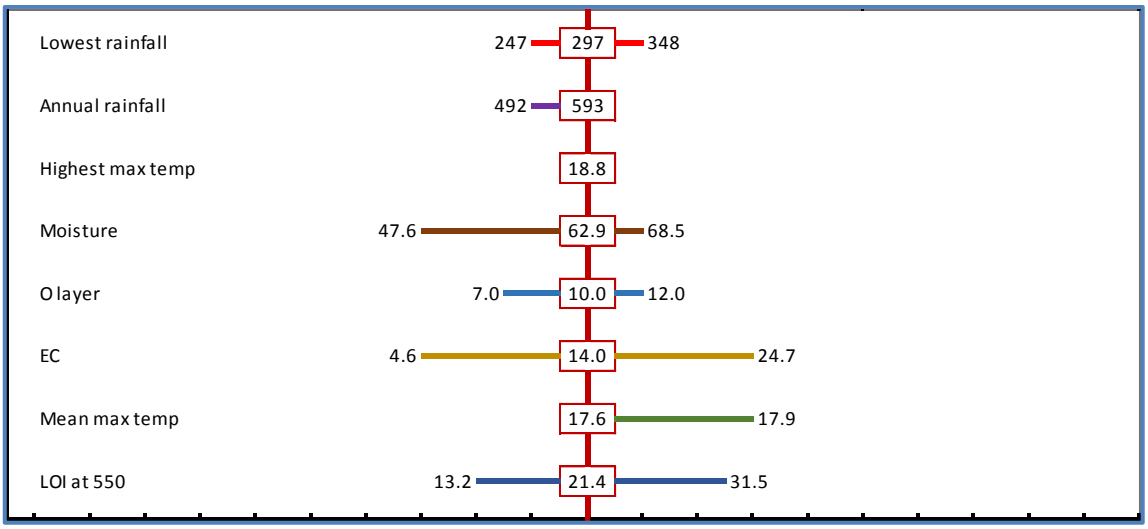


Figure 6A.3.3: *Disphyma crassifolium* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

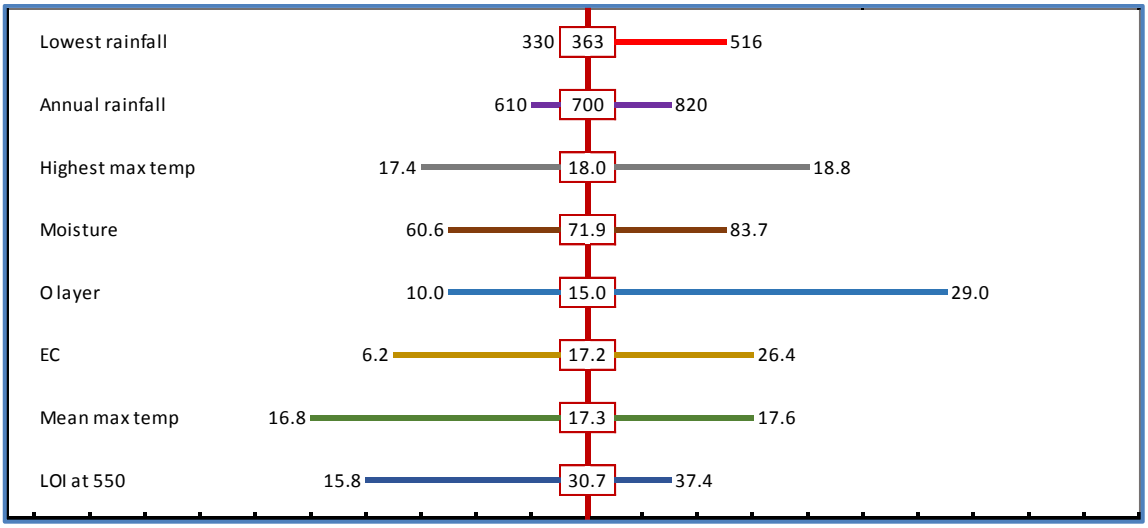


Figure 6A.3.4: *Gahnia filum* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

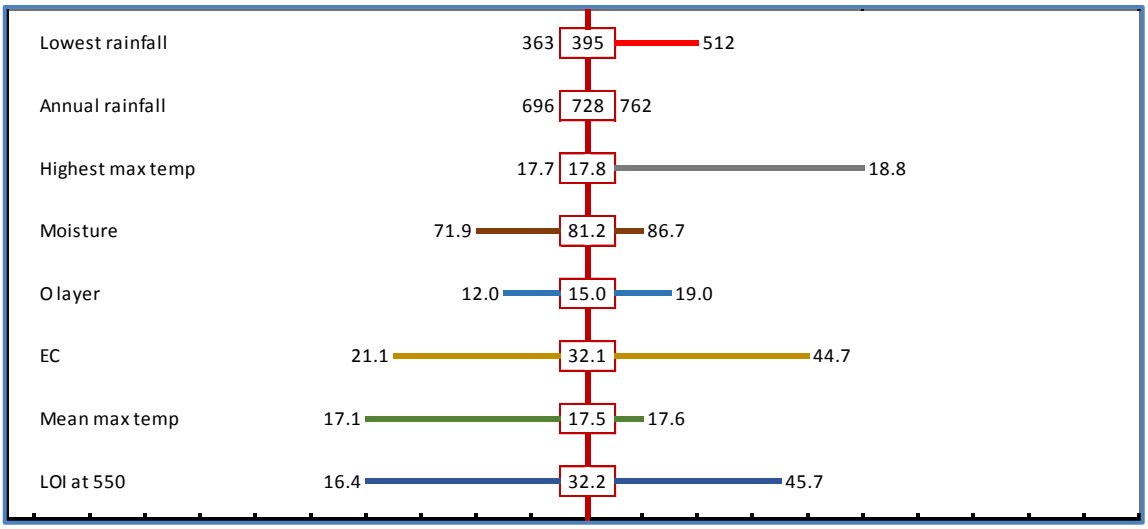


Figure 6A.3.5: *Hemichroa pentandra* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

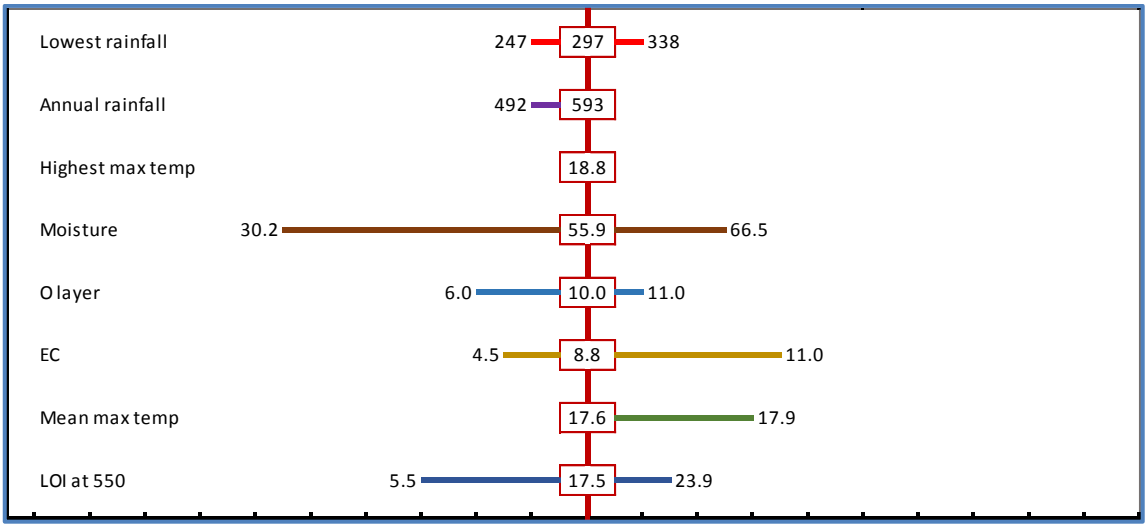


Figure 6A.3.6: *Sarcocornia blackiana* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

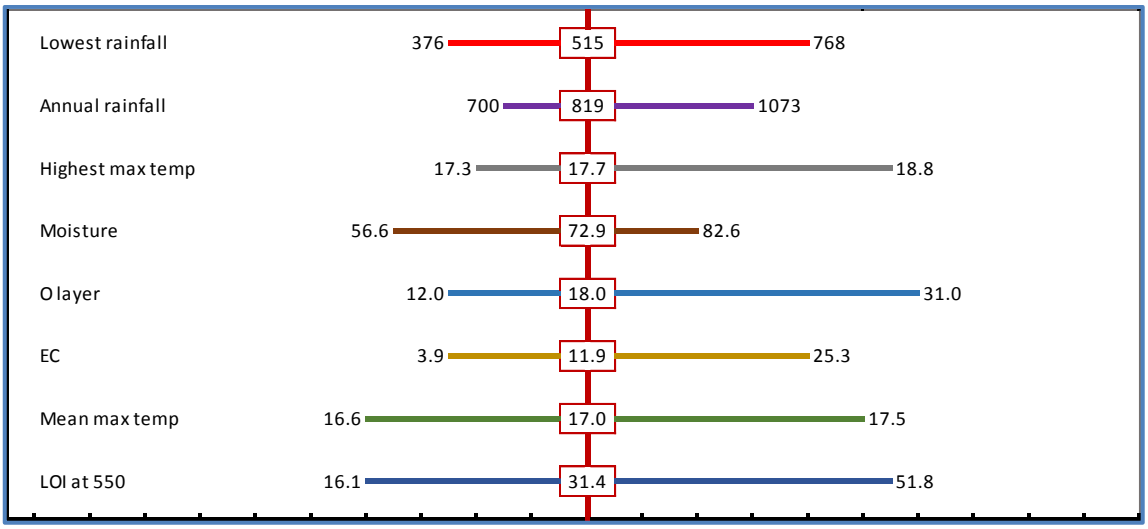


Figure 6A.3.7: *Selliera radicans* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

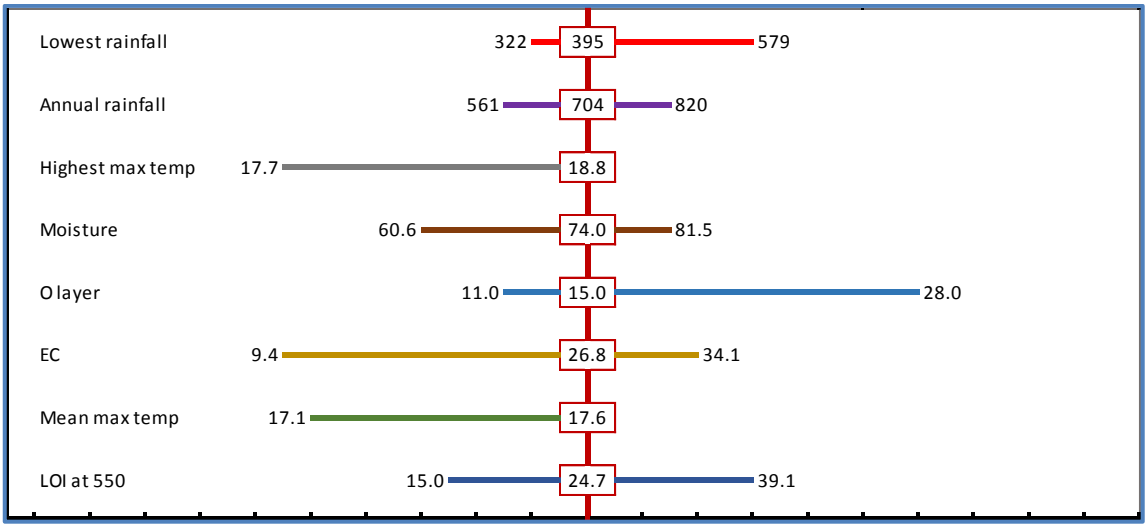


Figure 6A.3.8: *Suaeda australis* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

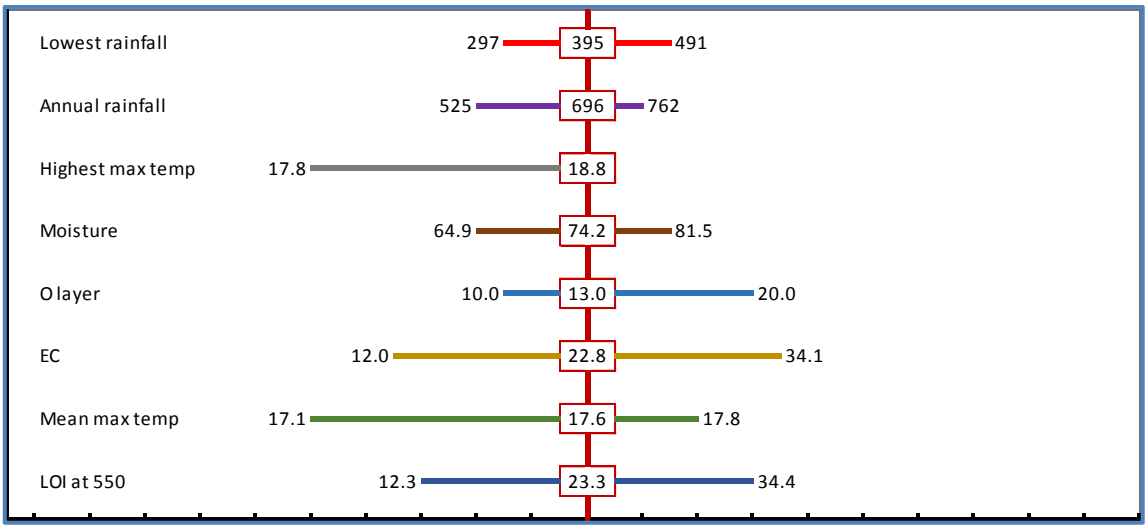


Figure 6A.3.9: *Tecticornia arbuscula* decision chart. The median of each individual attribute is centred on the chart with bars that represent the interquartile range (the "ecological/habitat range" of the plant species). The value of the 1st quartile is presented on the left, the value of the 3rd quartile is displayed on the right of the median.

Chapter 7

Saline and fresh water pulse trial

Chapter 7 – Table of contents

Chapter 7: Saline and fresh water pulse trial in a Tasmanian coastal saltmarsh environment

7.1 Introduction

Sea-level has increased over the last 100 years and is expected to rise at a greater rate over the next 50 years (IPCC 2014). Anthropogenic induced climate change will see alterations to weather patterns which will result in greater fluctuations between dryer and wetter conditions, with some areas receiving increased rainfall, whilst others experience reduced rainfall (Grose *et al.* 2012). Tasmanian coastal saltmarshes are at the forefront of these changes, and effects will vary locally (Prahalad 2009; Mount *et al.* 2010). Rising sea-level is expected to result in greater frequency and duration of inundation and, in many cases, increased soil salinities in coastal wetlands. Higher relative sea-level will result in shifts in vegetation composition of tidal marshes from less salt-tolerant plant species to more salt-intolerant species (Prahalad *et al.* 2011). Conversely, increased rainfall events can result in decreased salinities, which may lead to shifts in vegetation composition from salt tolerant to salt intolerant species.

Studies in the northern hemisphere, particularly in the USA have examined the impacts of increased salinity and sea-level rise (Crosby *et al.* 2016). Here, much of the focus has been on the graminoid group of marshes (*Phragmites* spp., *Spartina* spp. *Schoenoplectus* spp.), for example, Baldwin and Mendelssohn (1998), Howard and Mendelssohn (2000), Morris *et al.* (2002), Sharpe and Baldwin (2012), Woo and Takekawa (2012), Morzaria-Luna *et al.* (2014), Weston (2014). Other work has focused on climate change generated extreme weather events on coastal wetland vegetation (Zedler 2010). In Australia, a recent report has shown that coastal wetlands are already impacted by climate change, insomuch that saltmarsh and mangrove distributions are in rapid change often consistent with current increases in seal-level rise (Laurance *et al.* 2011), temperature and atmospheric carbon dioxide (Saintilan *et al.* 2018). Support for these findings comes from work by Rogers *et al.* (2014), Saintilan *et al.* (2014), Kelleway *et al.* (2017) and others, some with a focus on mangrove (e.g. *Avicennia marina* (Forssk.) Vierh) distribution and encroachment into saltmarshes. Mangroves are currently not present in Tasmania as cooler night temperature preclude their establishment (Kirkpatrick & Glasby 1981), so in the short-term, mangrove intrusion into saltmarshes

should not be an issue. However, as elsewhere in Australia, overnight minimum temperatures are slowly rising (Bureau of Meteorology 2019).

Studies of climate change impacts in Tasmanian coastal saltmarshes include Mount *et al.* (2010) who studied the broad effects of sea-level rise on coastal marshes in the Circular Head area of NW Tasmania. Their work had a strong focus on local community, benefits of coastal marshes, impacts of sea-level rise, communicating the key take-home messages and ongoing and future management options. Key findings include a net rise in sea-level of 5.4cm, with a landward shift of 12m in the last 50 years. This has resulted in a landward movement of *Melaleuca* (T-tree or paperbark) species, a key coastal wetland plant, loss of long living species such as *Tecticornia arbuscula* and *Melaleuca* spp. and erosion of old shorelines which have been dated 26,000 to 36,000 years BP (Mount *et al.* 2010). Prahalad *et al.* (2011) conducted a study on coastal saltmarshes of the upper Pitt Water region in Tasmania's southeast. They found that a noticeable increase in windspeeds and temperatures, together with a discernible decrease in annual rainfall in SE Tasmania since 1975, has resulted in a shift to a more salt-tolerant and inundation-tolerant vegetation community composition. Predominant vegetation changes include *T. arbuscula* replaced by *Sarcocornia quinqueflora,* and *S. quinqueflora* yielding to *Samolus repens* or bare ground. Coastal erosion in the upper Pitt Water marshes resulted in a 5% loss of saltmarsh area since 1975, however, there was a small gain of 1% in a prograding section during the same period (Prahalad *et al.* 2011).

Tasmania's coastal marshes are important roosting locations for migratory birds at the end of both international (Greenberg *et al.* 2014) and national flyways (Mondon *et al.* 2009) and any alteration or loss to coastal marshes will impact bird numbers and future survivability (Mondon *et al.* 2009; Zedler 2010; Prahalad 2014; Prahalad *et al.* 2015). Furthermore, Tasmanians enjoy coastal living, which in many cases has come at the expense of coastal marshes. These marshes have been filled in – so called reclaimed – become prime building land and are now home to coastal housing developments, resorts and farming (Torio & Chmura 2013). Remaining marsh areas now face considerable "accommodation/coastal squeeze" (Doody 2004; Pontee 2013; Torio & Chmura 2013) and in future may be restricted to either restoration or "natural" relocation inland.

Considering this, there needs to be a better understanding of sea-level rise and climate change impacts particularly of increasing/decreasing salt tolerance of saltmarsh plants and changes that can occur in marsh soils.

7.1.1 Sea-level rise and climate change

Increasing salinity

Sea-level rise will lead to an increase of the extent and frequency of inundation of coastal saltmarshes (Laurance *et al.* 2011). The lower zone of saltmarshes may not be as greatly impacted as the middle and upper zones, as regular inundation already has an influence on plant species incidence and the composition of vegetation communities in this zone. Currently however, the middle and upper zones of coastal marshes experience less inundation, and these two zones may be greatly impacted by an increase in the regularity of inundation, both temporal and extent, therefore increasing salinity.

Decreasing salinity

Anthropogenic forced climate change is altering weather patterns which may lead to increased precipitation in several regions and decreased precipitation in others (Grose *et al.* 2012; IPCC 2014). In some cases, increased precipitation may have a deleterious effect on halophilic vegetation by reducing salinity to levels that individual species are unaccustomed and intolerant. This can result in functional stress of halophytes, followed by death. A further consequence may be expanding ground surface exposure (decreasing ground cover by plants), thus promoting erosion and increased sediment contamination of waterways followed by sediment deposition and smothering of saltmarsh plants (Zedler 2010).

7.1.2 Questions and study aims

At present, the low zone of coastal saltmarshes is regularly inundated, temporally or by extent. However, the middle and upper zones incur less frequent inundation, particularly the upper zone which is mostly impacted by air-borne salt. The frequency of saline intrusion into the middle and upper zones is expected to increase with sea-level rise, while climate change presents opportunities for increased precipitation. Both scenarios can alter the salinity levels in coastal saltmarshes from current levels to the possible detriment of well-established individual plants.

Questions

The aim of this experiment is to determine how plant species will be impacted by salinity changes, thus providing an understanding into the extent of potential loss in plant species, and in many ways, the potential decline of coastal saltmarsh vegetation communities around Tasmania. From this two questions arise:

1. How will selected coastal saltmarsh vegetation communities react to increasing inundation (therefore increasing salinity) because of sea-level rise?
2. How will selected coastal saltmarsh vegetation communities react to increasing rainfall (therefore decreasing salinity) because of climate change?

Study aims

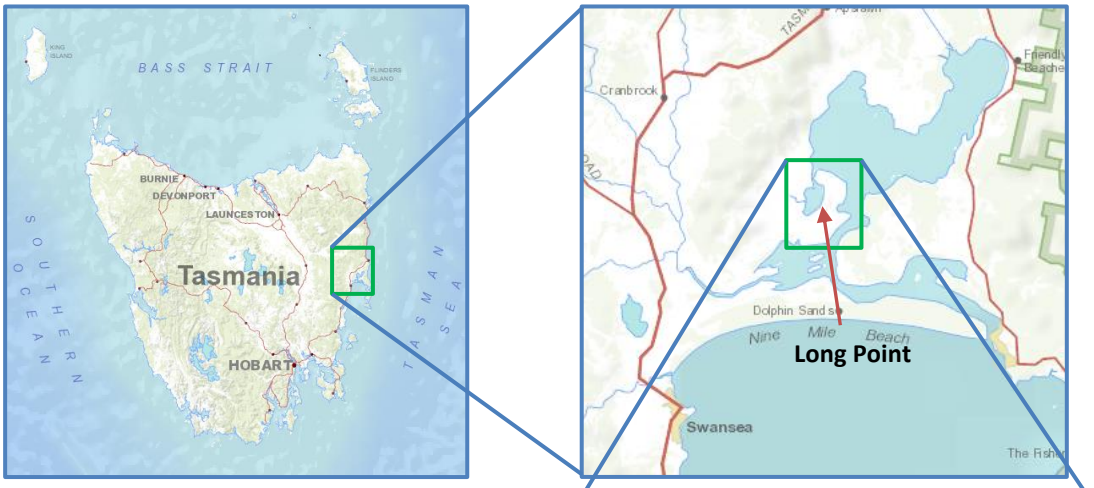
- To identify which coastal saltmarshes vegetation communities will be more robust in response to sea-level rise or climate change.
- To investigate what modifications or trends may occur to edaphic factors of Tasmanian coastal saltmarshes in times of sea-level rise and climate change.

7.2 Methods

Rather than conducted in a laboratory environment where it is often difficult to replicate true natural effects, this study was carried out in the field as an open air, natural environmental field trial, where no modification to plots of any kind were undertaken. Therefore, all plots were subject to similar precipitation, evaporation, temperature and sunshine, factors difficult to replicate or control in the laboratory.

7.2.1 Location

Long Point (Moulting Lagoon) on Tasmania's east coast (Figures 7.1 to 7.3), was selected as a suitable site to conduct the saline and fresh water pulse trial over a 12 month period. The site is owned by a registered environmental organisation, the Tasmanian Land Conservancy (TLC). The area has limited/restricted access, is usually closed to the public, has a range of vegetation communities and the TLC is supportive of field research on its holdings. The site necessitated reasonable access to a variety of vegetation communities and accessible by 4x4 vehicle to avoid carrying 25 litre drums of water long distances.



Figures 7.1 (above) and **7.2 (above right):** Location of study site.
Map source: DPIPWE (2018).

Figure 7.3: Location of study site plots (**orange** circle) at Long Point.
Aerial photo source: DPIPWE (2018).

7.2.2 Vegetation communities and target species

Vegetation communities

In this study, four typical halophytic vegetation communities were selected for investigation (vegetation community code see Chapter 3) (Figures 7.4 to 7.7):

- ASQ – *Sarcocornia quinqueflora* – designated as **SQ**;
- AHM – herb mix (*S. quinqueflora, Sarcocornia blackiana* and *Disphyma crassifolium*) – designated as **HM**;
- ASH – succulent shrubs (*Tecticornia arbuscula*) with understorey herbs (*S. quinqueflora, S. blackiana, D. crassifolium*) – designated as **TA**;
- AGH – saline grassland (*Austrostipa stipoides*) with herb mix understorey (*S. quinqueflora, S. blackiana, D. crassifolium*) – designated as **GL**.

Figure 7.4: Vegetation community ASQ, plot designation **SQ**; single species – *Sarcocornia quinqueflora*.

Figure 7.5: Vegetation community AHM, plot designation **HM**; mixed herbs species – *Sarcocornia quinqueflora, Sarcocornia blackiana, Disphyma crassifolium*.

Figure 7.6: Vegetation community ASH, plot designation **TA**; mixed species – *Tecticornia arbuscula, Sarcocornia quinqueflora, Sarcocornia blackiana, Disphyma crassifolium.*

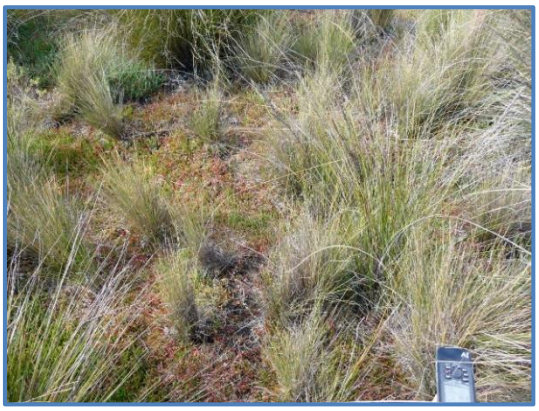


Figure 7.7: Vegetation community AGH, plot designation **GL**; mixed species – *Austrostipa stipoides, Sarcocornia quinqueflora, Sarcocornia blackiana, Disphyma crassifolium.*

Target species

Four plant species, *D. crassifolium, S. blackiana, S, quinqueflora* and *T. arbuscula* were the prime focus of the study (Figures 7.8 to 7.15). Each was chosen as they were thought to be very salt-tolerant and response expectations were high following exposure to fresh water.


Figures 7.8 & 7.9: Plant species *Disphyma crassifolium* (roundleaf pigface).


Figures 7.10 & 7.11: Plant species *Sarcocornia blackiana* (thickhead glasswort).


Figure 7.12 & 7.13: Plant species *Sarcocornia quinqueflora* (beaded glasswort).


Figure 7.14 & 7.15: Plant species *Tecticornia arbuscula* (shrubby glasswort).

7.2.3 Treatments

Trial plots were 1 metre x 1 metre in area and all located within a 100 metres radius overall. Each plot was boxed with timber to confine water infiltration and prevent runoff. Three treatments were applied to each community – increasing salinity, decreasing salinity and control. Each was replicated twice – therefore six plots per vegetation community – all within a 30 metres radius by vegetation community;

Treatments were:

- Increasing salinity – 50 litres of marine water (collected at Swansea, the closest accessible source of seawater) applied fortnightly;
- Decreasing salinity – 50 litres of fresh (potable) water (collected at Hobart) applied fortnightly; and
- Control – nil application of any additional water other than natural rainfall.

7.2.4 Sampling

The following sampling regime was applied to the study:

- Prior to the initial water application and at the end of the trial, random sampling of soils (three organic layer samples) and plant species (leaf/tissue samples) were undertaken within each plot;
- Soil samples (three from the organic layer) were collected from each plot at weeks 20 and 43;
- Six samples of fresh and marine water, (n = 12) collected at each water application (n = 27) over the duration of the study; and
- Rain gauges were installed in each vegetation community to measure any local (micro) variations in rainfall. Rainfall data was collected at each visit and collated to a spreadsheet along with rainfall recorded at Bureau of Meteorology (BOM) weather stations at Swansea and Friendly Beaches for comparison (Figure 7.16).

Originally, the envisioned study period was to commence in December 2016 and conclude in December 2017. However, access to the site became limited during winter due to boggy conditions, so the study was suspended for a period of four months from

June to September 2017. In compensation, the study continued to the end of April 2018.

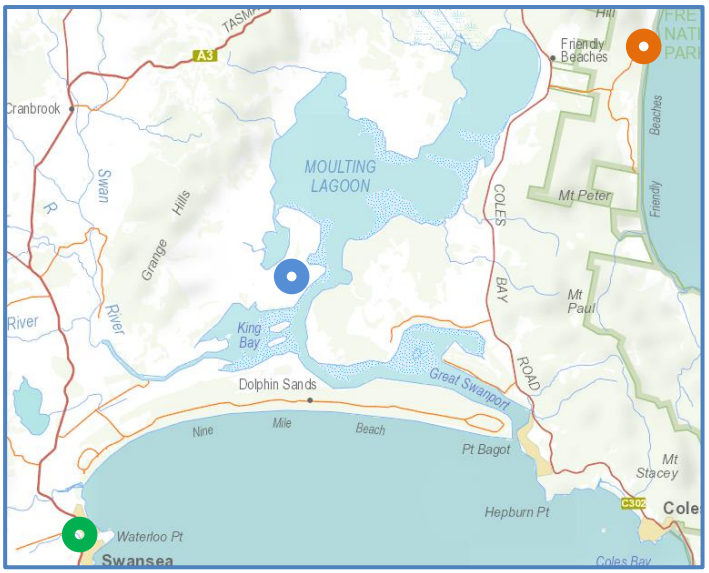


Figure 7.16: Bureau of Meteorology weather stations.

- Swansea
- Friendly Beaches
- Study site

Map source: DPIPWE (2018).

7.2.5 Laboratory analysis

Collected samples were analysed in the laboratory as follows:

- Initial (December 2016) soil samples were analysed for bulk density, composition, moisture, pH, EC and LOI at 550°C (LOI550);
    - Analysis of pH and EC per Rayment and Lyons (2011), see Chapter 4 (Soils of Tasmanian coastal saltmarshes);
    - Bulk density, composition, moisture and LOI550 analysis per methods in Chapter 4, Section 4.2.3.
- Throughout the study, soil samples were analysed for pH and EC to record temporal change;
- Conclusion (April 2018) soil samples were analysed for pH and EC only, testing as per previous;
- Conclusion samples were re-analysed for EC to confirm the original analysis (see Results and discussion – Soil, Section 7.4.3 below);
- Applied water samples (saline and fresh) were analysed for pH and EC; and
- Initial and conclusion plant samples were analysed for pH and EC to determine trends.

Plant samples

As this project was self-funded, a simplified analysis process was devised to determine pH and EC values of plant leaf samples. Emphasis was given to determine the temporal change of pH and EC following the marine/fresh water treatments. Six leaf cuttings (from individual plants) from each plant species were taken from each plot (n = 24) at the start and end of the watering process. The six cuttings were split to two sub-samples (n = 264), each sub-sample weighed and then combined with deionised water at a ratio of one part plant sample to 10 parts of water. The sub-sample was blended using a hand-held stick blender until all plant material had been pulverised and then allowed to stand for 30 minutes. Three pH measurements using a temperature compensated pre-calibrated Hana Instruments soil pH meter (model 99121), and three EC measurements using a temperature compensated pre-calibrated Hanna Instruments EC/TDS/NaCl/Resistivity meter (model HI 98192) were taken of each (sub-sample) solution, giving six measurements of each attribute from each sample. The mean of the six readings was taken to be the pH/EC of each plant leaf sample.

A note on calibration: Prior to use each day, each meter (EC and pH) was calibrated using EC buffers of 0.084, 1.413 and 12.88dS/m, and pH buffers of 4.0 and 7.01. Calibrations were checked prior to measurement using EC buffers 0.084 and 12.88, and both pH buffers as this was the expected range of the plant leaf observations. The meters were checked during measurements and recalibrated whenever necessary.

7.2.6 Data management

Rainfall

All recordings entered to Excel spreadsheet and prepared for presentation as charts.

Soil

Observations of pH and EC (3 sub-samples x 3 observations each, therefore nine readings) entered to Excel spreadsheet, means calculated for each sample and used in analysis and presentation as charts. Bulk density, moisture, composition and LOI550 data retained for Chapter 3 and Chapter 5 (Carbon stock of Tasmanian coastal saltmarshes).

Applied water

For each application of water, pH and EC observations (6 x marine, 6 x fresh) were

entered to Excel spreadsheet, means were calculated and used in analysis and presentation as charts.

Plants

The observations of pH and EC from each plant sub-sample were entered to an Excel spreadsheet, means calculated for each sample and used in analysis.

7.3 Statistical analysis

Statistical analysis of the collected data includes:

- Data recorded to MS Excel spreadsheets;
- Charts displaying rainfall totals for the study period with that sourced from adjacent BOM weather stations;
- Charts demonstrating variations of pH and EC observations of the applied marine and fresh water;
- Charts showing temporal changes in soil pH and EC over the study period;
- Charts displaying the overall change (from start to end of study period) in plant species pH and EC; and
- A two-sample equal variance t-test to determine significant difference between the means of observed commencement and conclusion pH and EC values for both plant species and soils from each of the three treatments.

Results include:

- An awareness of microscale variations in rainfall at the study site;
- An appreciation of the degree of change in soil and plant leaf chemistry, and soil/plant relationships due to increasing/decreasing salinity episodes (and control); and
- Confirmation of plant species resilience to temporal change of soil pH and EC conditions with a view on survivability and endurance of different plant species due to increasing inundation and climatic change impacts.

A series of before and after photos of all plots are presented in Appendix 7A.1

7.4 Results and discussion

The following section incorporates a combination of both results and discussion as some results require comment before progressing to a subsequent result. Within the following text, rainfall is expressed as mm (millimetres), pH values are standard pH units, while EC vales are expressed as dS/m (decisiemens per metre). All means are reported to standard error. **Note:** the term range is used to describe the minimum and maximum values (the limits) of an observation, while the term spread describes the difference between the limits (the extent) of an observation. Results have been comprehensively reported.

7.4.1 Rainfall

Rainfall for the study period, December 2016 to April 2018, is presented in Figure 7.17.

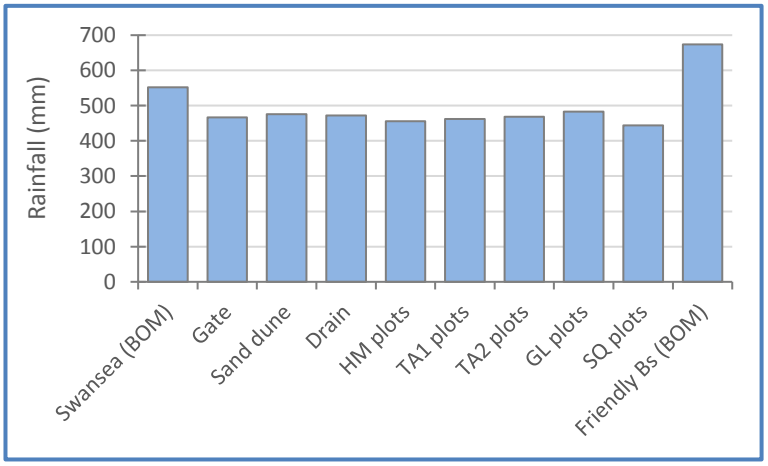


Figure 7.17: Rainfall (mm) by individual site. Site order west (Swansea BOM) to east (Friendly Beaches (BOM).

It was expected that rainfall at the study locations (gate to SQ plots inclusive) would have been mid-range between the two BOM weather recording stations – annual rainfall Swansea = 593.3mm, Friendly Beaches = 690.5mm (BOM 2016) as general rainfall on Tasmania's east coast predominantly originates from "east coast lows" (intense low pressure systems that occur off the eastern coast of Australia … and Tasmania) (BOM 2012). The lower than expected rainfall could be a result of evaporation from rain gauges that occurred between data collection, or the study site's position in the landscape as it is situated in rain shadows leeward of westerly and easterly rain events. However, as the study site rain gauges were all collected at the same time, the data suggests that variations occur at a microscale level, particularly between the HM plots and SQ plots as this distance did not exceed 100 metres of open country,

with all gauges positioned above vegetation height.

7.4.2 Applied water

Marine water

The mean pH and EC of each marine water application are presented in Figures 7.18 and 7.19.

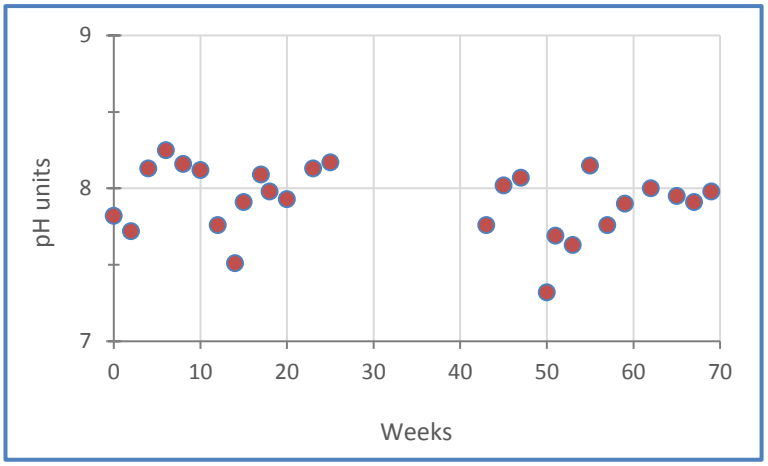


Figure 7.18: pH of each application of marine water by week. The interval between weeks 25 and 43 is the period of study suspension.

The pH values ranged 7.51-8.16, 0.65, mean 7.92 ± 0.043. It is unclear to the reason for variations between collections. Occasionally, decaying seaweed matter was present at the marine water collection point (possibly increasing acidity levels) which may have lowered the pH from the standard value of 8.1 for seawater.

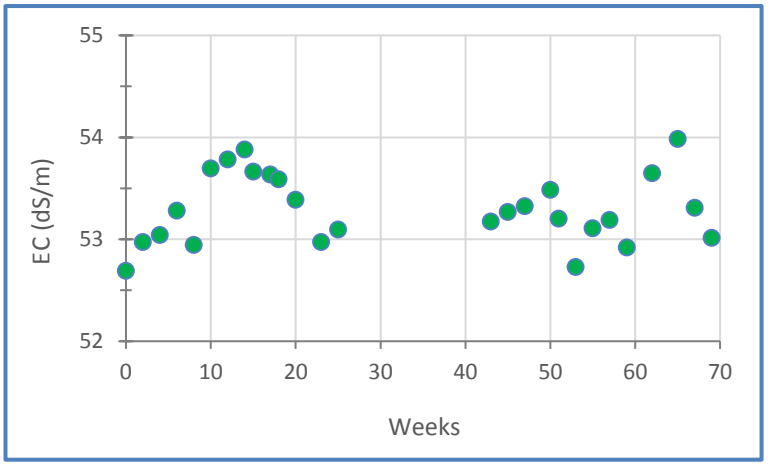


Figure 7.19: EC (dS/m) of each application of marine water by week. The interval between weeks 25 and 43 is the period of study suspension.

The EC values are in a tight range, 52.69-53.99, 1.30, mean 53.30 ± 0.067. Again, it is unclear why difference between applications occurred; collections were always early mornings, however, often at different points of the tidal cycle. Fresh water runoff following rain may have impacted some EC values.

Fresh water

The mean pH and EC of each fresh (potable) water application are presented in Figures 7.20 and 7.21.

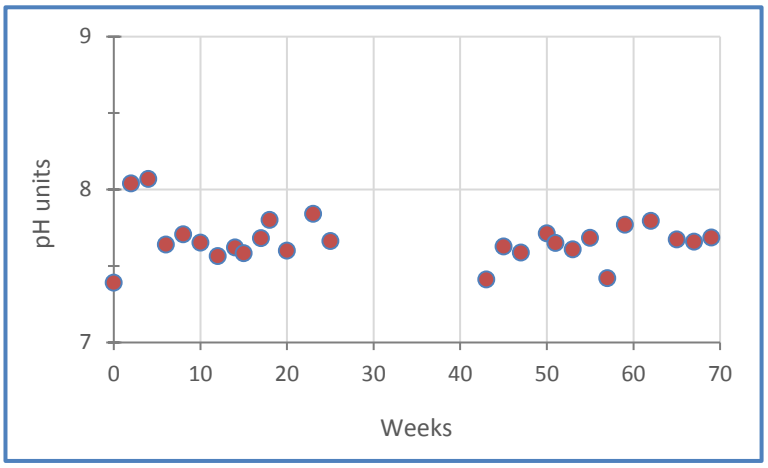


Figure 7.20: pH of each application of fresh water by week. The interval between weeks 25 and 43 is the period of study suspension.

The pH values ranged 7.39-8.07, 0.68, mean 7.67 ± 0.030. It is unclear as to why there are variations between collections.

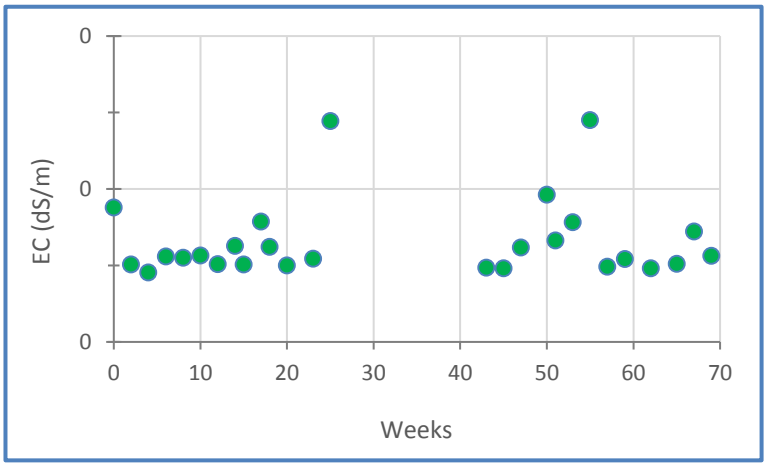


Figure 7.21: EC (dS/m) of each application of fresh water by week. The interval between weeks 25 and 43 is the period of study suspension.

The EC values of applied freshwater were in a constrained range (0.045-0.145, 0.100, mean 0.066 ± 0.005). Again, it is not clear why variations between applications occurred.

7.4.3 Soil pH and EC

The pH and EC of soil samples from individual vegetation communities are presented in Figures 7.22 to 7.45. Figures are provided by vegetation community, individually by pH and EC, individually by treatment (increasing salinity, control, decreasing salinity). All pH plots have a similar scale (4 to 8) as do EC plots (0 to 40).

Community SQ (Sarcocornia quinqueflora)

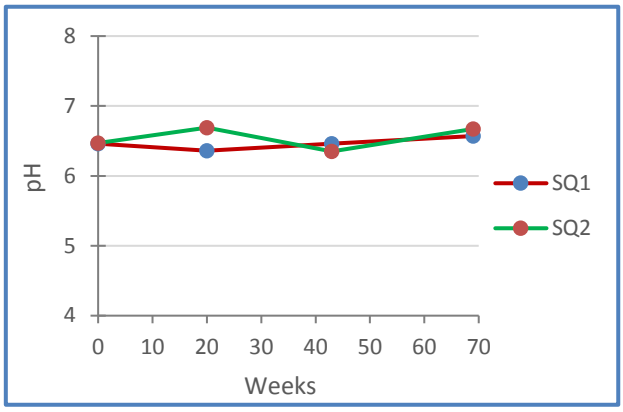


Figure 7.22: Community **SQ**, pH – increasing salinity.

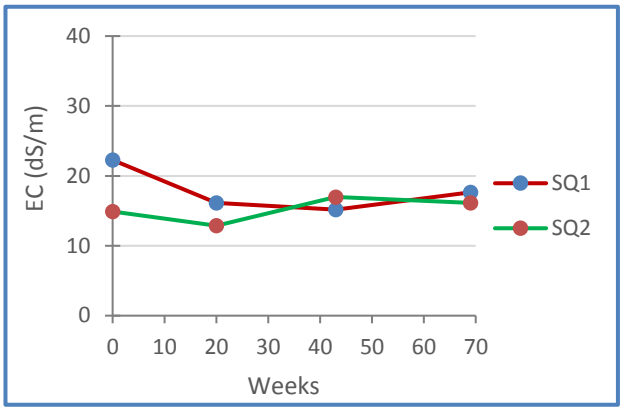


Figure 7.23: Community **SQ**, EC – increasing salinity.

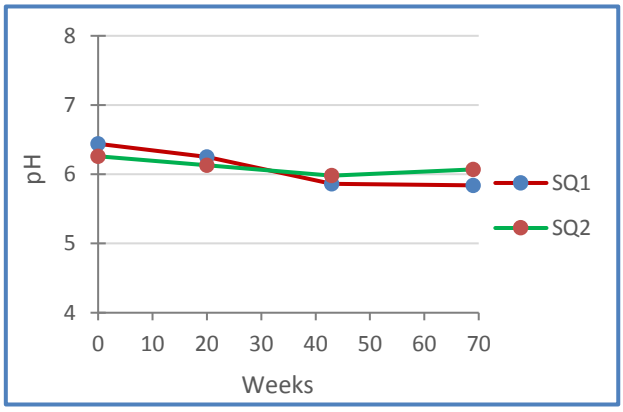


Figure 7.24: Community **SQ**, pH – control.

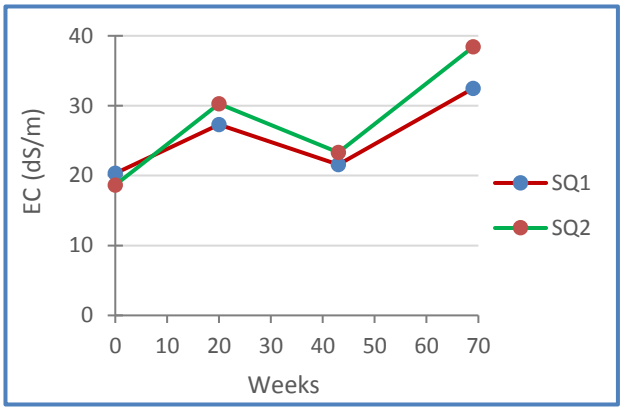


Figure 7.25: Community **SQ**, EC – control.

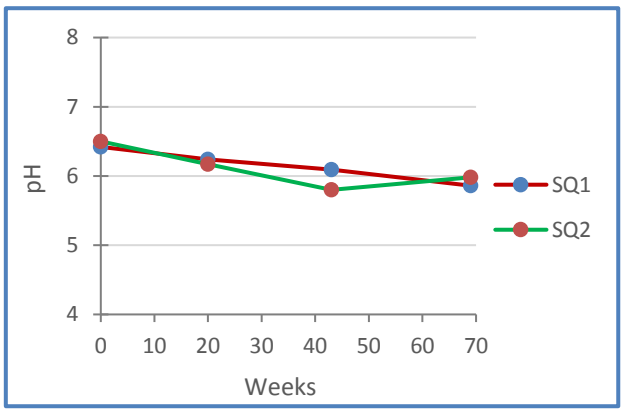


Figure 7.26: Community **SQ**, pH – decreasing salinity.

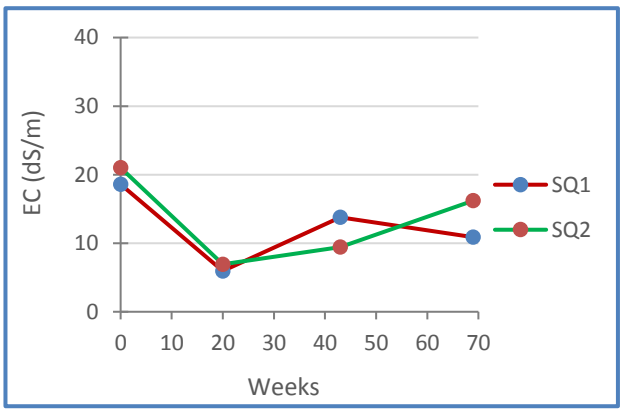


Figure 7.27: Community **SQ**, EC – decreasing salinity.

Commencement pH values across all plots were similar (range 6.26-6.50, mean 6.43 ± 0.035); conclusion values for control and decreasing salinity plots were comparable (range 5.84-6.07, mean 5.94 ± 0.044), while increasing salinity treatment plots were greater by half a pH unit (mean 6.62) than the other two treatments. Commencement EC values were similar (slight difference in increasing salinity) (range 14.92-22.27, mean 19.30 ± 1.047). However, although conclusion pH values for increasing and decreasing salinity plots display similarities (range 10.88-17.66, mean

15.22 ± 1.216), control plots EC were more than two-fold greater (mean 35.45). This may be the result of moisture evaporation in control plots, thus increasing residue salts/EC values, while addition of water, although marine, maintained a sense of salt/EC equilibrium in the increasing salinity plots.

Community HM (mixed succulent herbs)

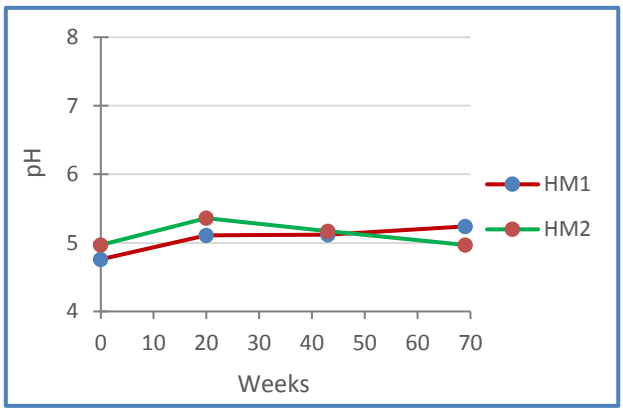


Figure 7.28: Community **HM**, pH – increasing salinity.

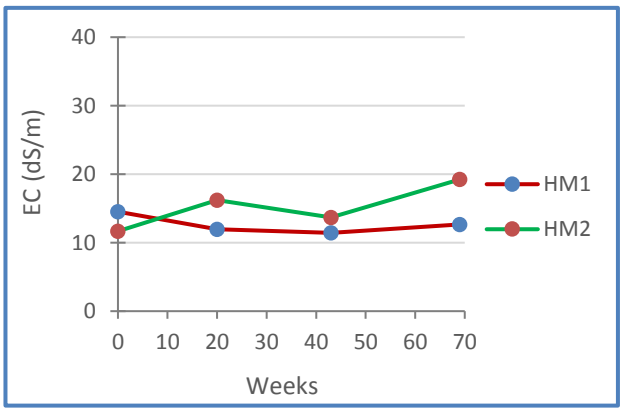


Figure 7.29: Community **HM**, EC – increasing salinity.

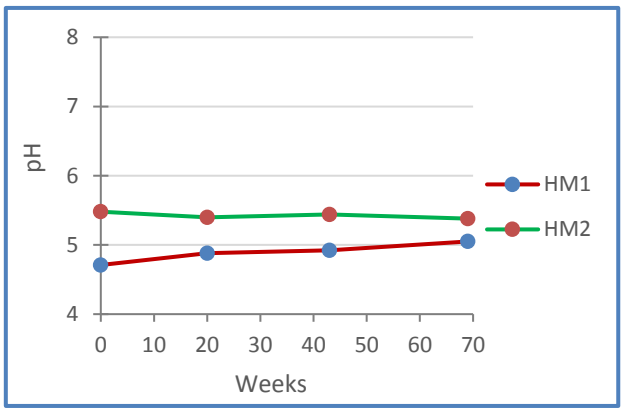


Figure 7.30: Community **HM**, pH – control.

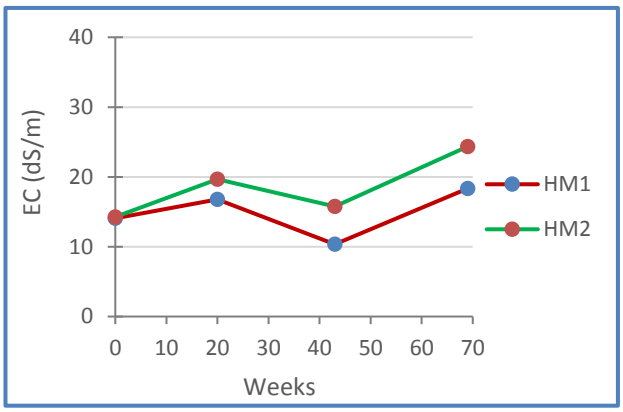


Figure 7.31: Community **HM**, EC – control.

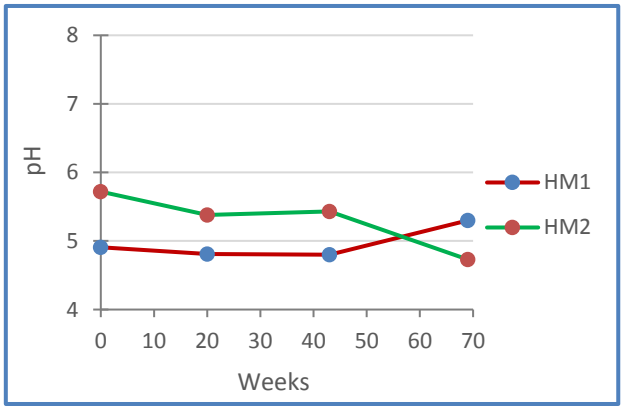


Figure 7.32: Community **HM**, pH – decreasing salinity.

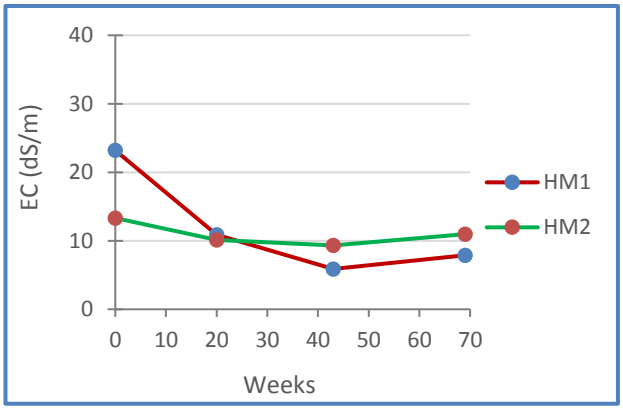


Figure 7.33: Community **HM**, EC – decreasing salinity.

Across all plots, mean pH commencement values (5.09 ± 0.168) were similar to conclusion values (5.11 ± 0.099) showing little overall shift in pH. While little change

was observed in increasing salinity and control plots, decreasing salinity pH values did fall. EC values within replicate plots did alter; increasing salinity rose slightly from a mean of 13.1 to 15.9, decreasing salinity fell two-fold from a mean of 18.3 to 9.4 (an expected fall). However, control plots EC rose from a mean of 14.3 to 21.4, again possibly due to evaporation, thus increasing salt/EC levels in the soil.

Community TA (Tecticornia arbuscula and mixed succulent herbs)

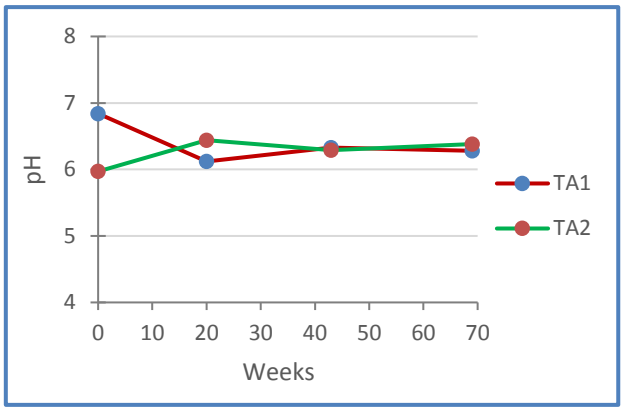


Figure 7.34: Community **TA**, pH – increasing salinity.

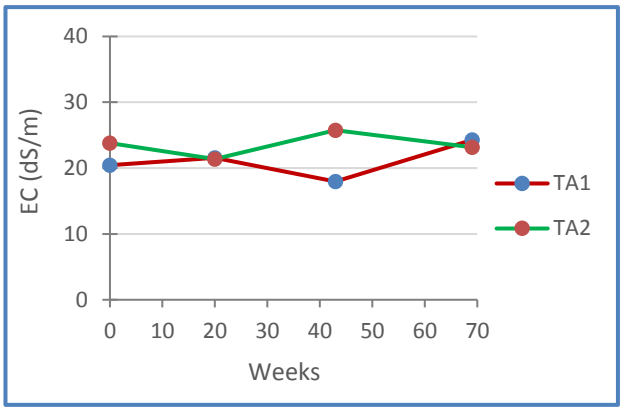


Figure 7.35: Community **TA**, EC – increasing salinity.

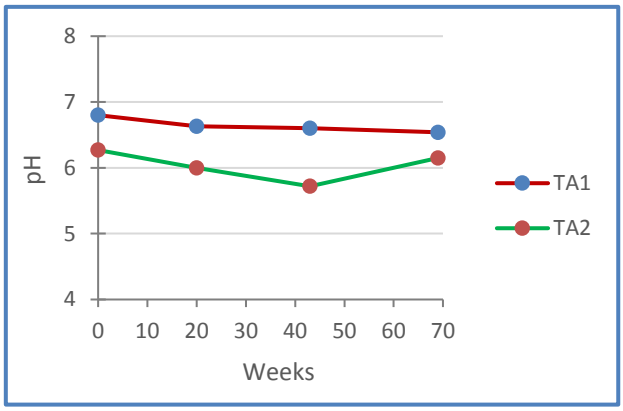


Figure 7.36: Community **TA**, pH – control.

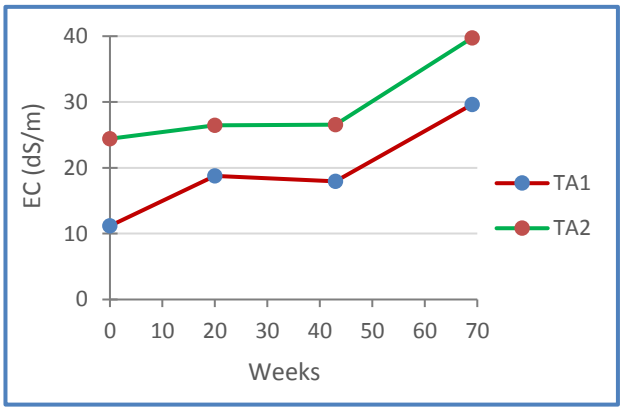


Figure 7.37: Community **TA**, EC – control.

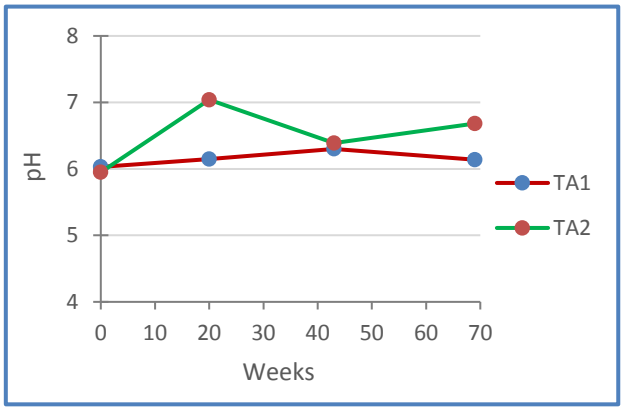


Figure 7.38: Community **TA**, pH – decreasing salinity.

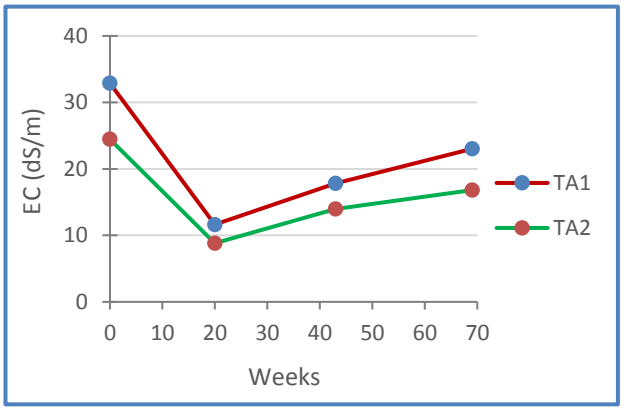


Figure 7.39: Community **TA**, EC – decreasing salinity.

Commencement pH mean (6.31 ± 0.168) was comparable to conclusion pH mean (6.36 ± 0.088), yet there were overall differences between treatments. Increasing salinity

pH fell 6.41 to 6.33, decreasing salinity plots pH increased from 5.99 to 6.41, while control plots slipped from 6.54 to 6.35. Overall, mean EC values increased from 7.05 ± 2.88 to 7.83 ± 3.20. However, changes within treatments were either insignificant or significant. Increasing salinity plots EC rose slightly from 22.13 to 23.71, decreasing salinity plots EC fell sharply from 28.67 to 19.92, while there was a two-fold jump in control plots EC from 17.80 to 34.69.

Community GL (grasslands and succulent herbs)

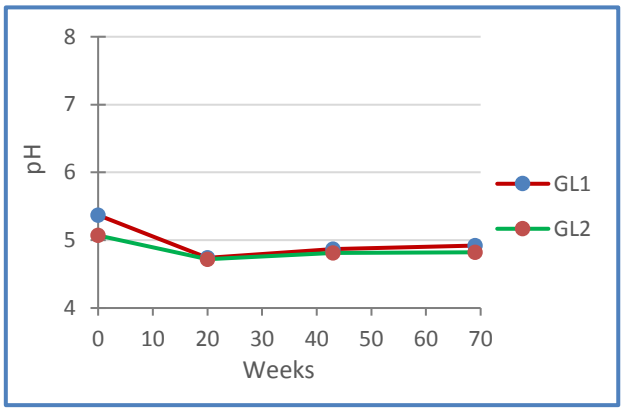


Figure 7.40: Community **GL**, pH – increasing salinity.

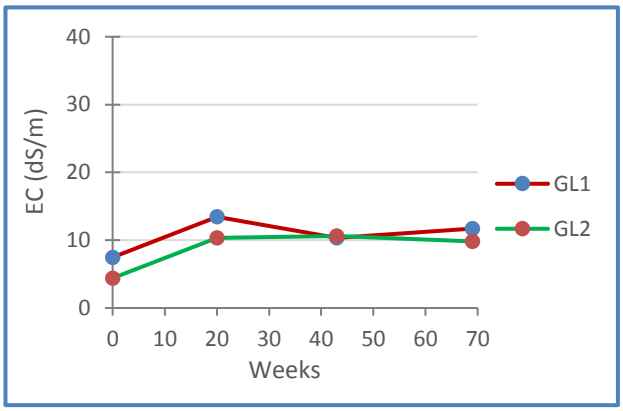


Figure 7.41: Community **GL**, EC – increasing salinity.

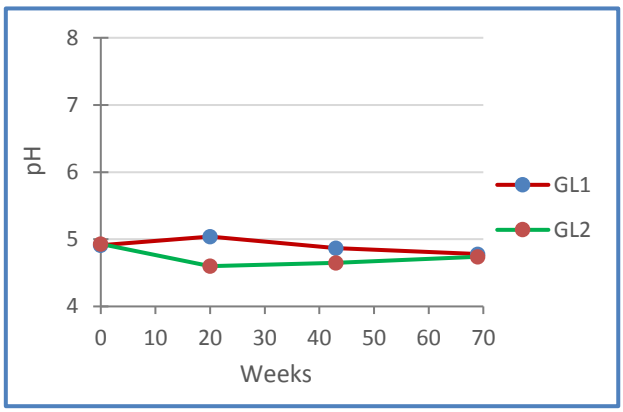


Figure 7.42: Community **GL**, pH – control.

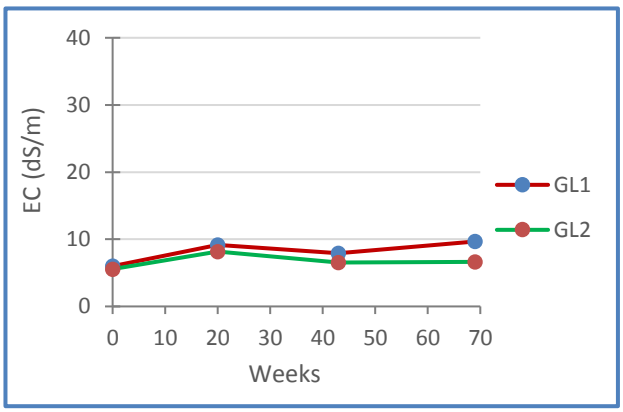


Figure 7.43: Community **GL**, EC – control.

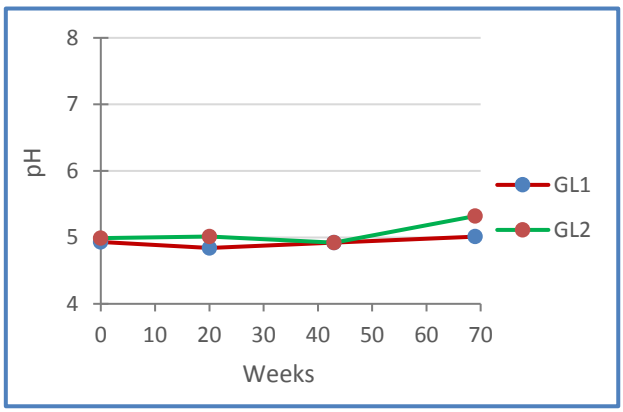


Figure 7.44: Community **GL**, pH – decreasing salinity.

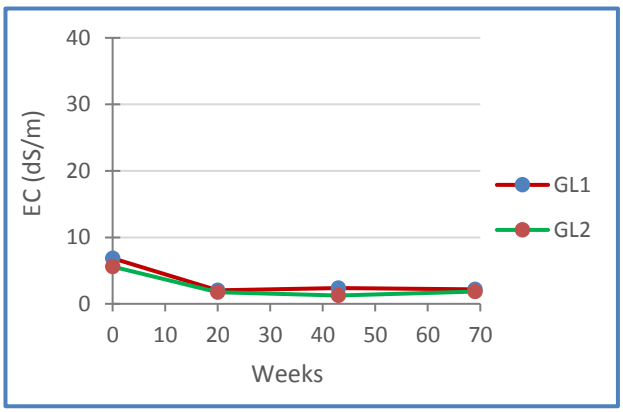


Figure 7.45: Community **GL**, EC – decreasing salinity.

Overall mean pH values fell slightly from 5.03 ± 0.071 to 4.93 ± 0.087. In each of increasing salinity and control plots, pH dipped (5.22 to 4.87, 4.92 to 4.76 respectively), while in decreasing salinity plots, pH increased from 4.96 to 5.17. In contrast, EC mean values increased, albeit slightly (5.98 ± 0.439 to 6.97 ± 1.706). Increasing salinity plots EC increased approximately two-fold (5.95 to 10.76), decreasing salinity plots EC fell sharply three-fold (6.23 to 2.01), while control plots EC increased from 5.78 to 8.16. The results here (GL plots) in some way contrast to that of the other three communities (SQ, HM and TA plots) where EC change is what one would have expected. In this case, increasing salinity from the addition of salt water, EC out-paced that of control (nil treatment) (81 to 41% respectively), while for decreasing salinity (addition of fresh water) EC values declined over 67%.

7.4.4 Summary – soils

pH

Across all vegetation communities and across all treatments, commencement pH values mean (5.72 ± 0.148) was comparable to conclusion values mean (5.64 ± 0.140), equal variance $t(46) = 0.355$, $p = 0.362$, a variation of just 1.40% (Table 7.1).

Table 7.1: Commencement and conclusion pH values by treatment. Means and standard error. Positive t-test values indicate conclusion pH values are lower than commencement pH values.

Treatment	Commencement pH	Conclusion pH	% change	t-test	p-value
Increasing salinity	5.74 ± 0.282	5.73 ± 0.287	-0.17	0.0186	0.493
Control	5.73 ± 0.288	5.57 ± 0.240	-2.79	0.4172	0.341
Decreasing salinity	5.68 ± 0.233	5.63 ± 0.229	-0.88	0.1644	0.436
Mean	5.72 ± 0.148	5.64 ± 0.140	-1.40	0.3549	0.362

Splitting treatments across all vegetation communities still recorded comparable means between commencement and conclusion pH values, this reinforced by the t-test results, none of which were significant (p-values 0.341-0.493). Therefore, it could be argued that whatever treatment was applied to soils in this study, there was little impact on pH values.

EC

However, differences do apply to EC values. Overall, there was little change to EC across all vegetation communities across all treatments. The conclusion means (16.57 ± 1.800), were similar to the commencement means (15.83 ± 1.548), equal

variance t(46) = -0.311, p = 0.379, a variation of just 4.7% (Table 7.2). Where variations did occur, they were within each individual vegetation community. Increasing salinity plots recorded an increase in EC of 12.7%, t(14) = -0.609, p = 0.276, control plots 51.4%, t(14) = -1.662, p = 0.059, while observations in decreasing salinity plots noted a decrease in EC of 38.4%, t(14) = 1.679, p = 0.058. However, none of the variations were significant, this identified by the t-tests.

Table 7.2: Commencement and conclusion EC(dS/m) values by treatment. Means and standard error. Positive t-test values indicate conclusion EC values are lower than commencement EC values; negative values indicate conclusion EC values are higher than commencement EC values.

Treatment	Commencement EC	Conclusion EC	% change	t-test	p-value
Increasing salinity	14.94 ± 2.465	16.83 ± 1.868	12.65	-0.6092	0.276
Control	14.31 ± 2.363	21.66 ± 3.734	51.36	-1.6619	0.059
Decreasing salinity	18.24 ± 3.271	11.23 ± 2.594	-38.43	1.6792	0.058
Mean	15.83 ± 1.548	16.57 ± 1.800	4.67	-0.3113	0.379

Overall, these were anticipated results, though not to the extent of that documented for control plots. Adding marine water to increasing salinity plots did raise the EC levels (it was expected higher) and adding fresh water to decreasing salinity plots did decrease EC levels (an expected outcome). The change in EC values to the control plots was expected to be minimal, perhaps 10%, which would have allowed for variations within and between collected soil samples. The observed increase of over 50% appeared excessive, however, a re-analysis of the samples in the laboratory confirmed the original results. A possible explanation is that the control plots continued to dry out as a response to evaporation, increasing residual salts, which resulted in a substantial increase in EC levels. The addition of water, whether marine or fresh, to the treatment plots appeared to maintain a degree of moisture equilibrium, irrespective of the type of water applied. This is supported by the minimal change (~12%) in EC values of the increasing salinity plots, the addition of marine water slightly increased EC values, yet moisture levels were maintained capping the increase of residual salts that could occur following evaporation. This study should would need to be carried out for a longer period and soil moisture values determined at regular intervals to test more comprehensively for any correlations between moisture and EC.

7.4.5 Plant species pH and EC

Plant species presence by vegetation community by treatment is presented in Table 7.3.

Table 7.3: Plant species presence in respective vegetation community by treatment. 1 = increasing salinity, 2 = control, 3 = decreasing salinity. A green tick (✓) indicates individual plant species presence.

	Vegetation community											
	SQ			HM			TA			GL		
Species	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Disphyma crassifolium				✓	✓	✓		✓	✓	✓	✓	✓
Sarcocornia blackiana				✓	✓	✓	✓	✓	✓	✓	✓	✓
Sarcocornia quinqueflora	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tecticornia arbuscula							✓	✓	✓			

The pH and EC of individual plant species are presented in Figures 7.46 to 7.89. Figures are provided by vegetation community, by species, by plot (as two replicates by vegetation community), individually by pH and EC. All pH plots have a similar scale (5 to 9), as do EC plots (0.5 to 2.5). Order of figures is that presented in soils (SQ, HM, TA and GL) with plant species order alphabetical where necessary.

Community SQ (Sarcocornia quinqueflora)

There was only one plant species present in this community.

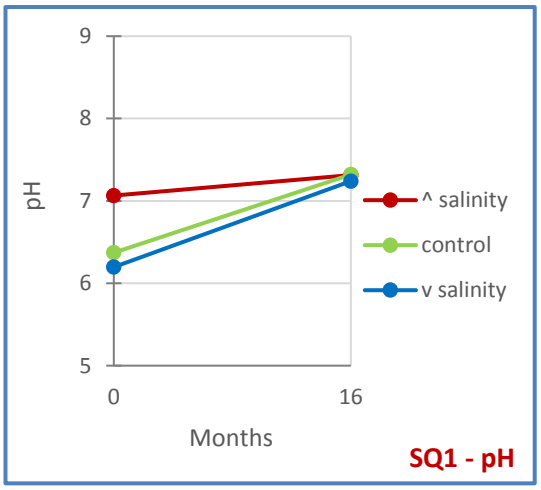


Figure 7.46: Community SQ, plot SQ1, pH, species *Sarcocornia quinqueflora*.

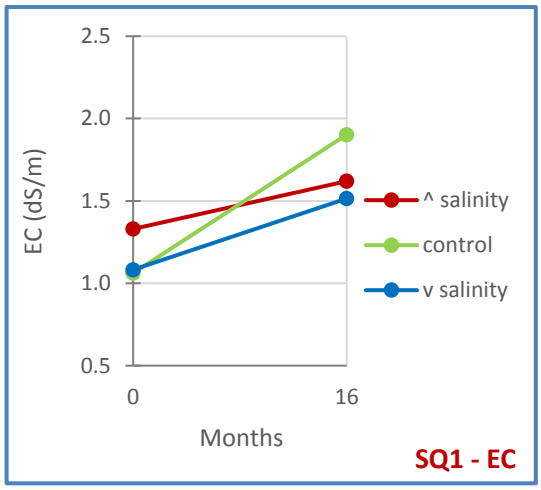


Figure 7.47: Community SQ, plot SQ1, EC, species *Sarcocornia quinqueflora*.

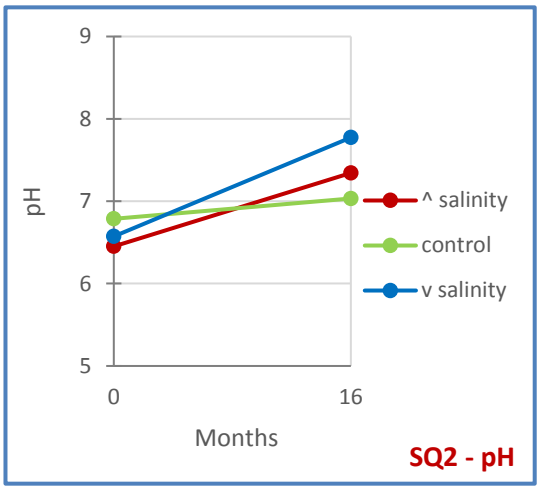


Figure 7.48: Community SQ, plot SQ2, pH, species *Sarcocornia quinqueflora*.

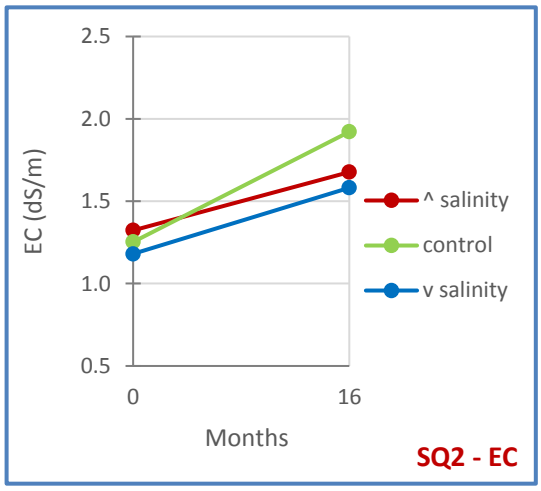


Figure 7.49: Community SQ, plot SQ2, EC, species *Sarcocornia quinqueflora*.

Both measurements, pH and EC, increased in value over the duration of the study. In terms of pH, an interesting observation is that in plot SQ1, commencement values were different, yet at conclusion, values were similar, while the opposite was observed in plot SQ2. In respect of EC, modest gains were made by increasing and decreasing salinity plots for *S. quinqueflora*, this in contrast to the EC measurements in soils where a slight downward trend was observed. However, the largest gain in EC was made by the control plots, the same evident in the soil data, suggesting that in some way, plant species EC levels were responding to the high soil EC levels.

Community HM (mixed succulent herbs)

There were three plant species present in this community, *D. crassifolium, S. blackiana* and *S. quinqueflora.*

Disphyma crassifolium

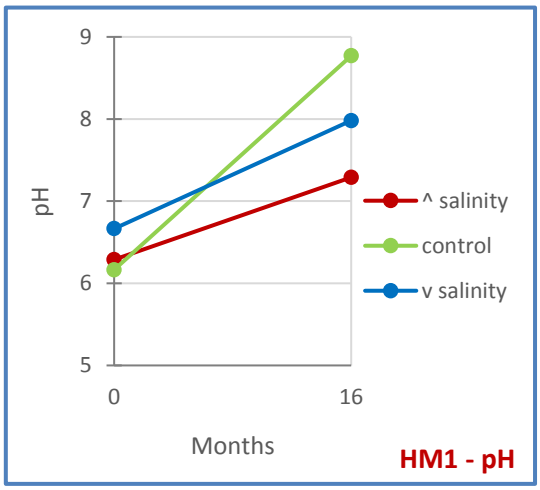


Figure 7.50: Community HM, plot HM1, pH, species *Disphyma crassifolium*.

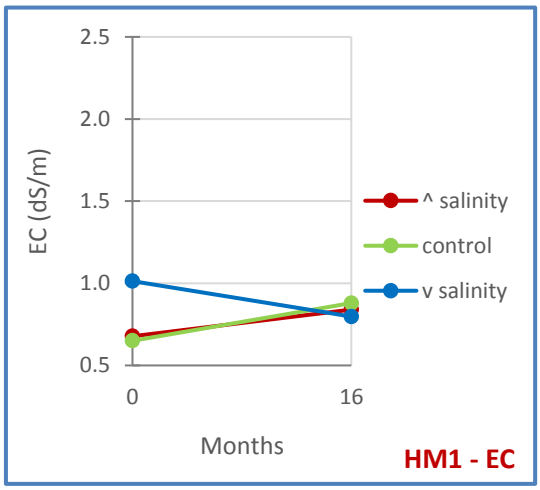


Figure 7.51: Community HM, plot HM1, EC, species *Disphyma crassifolium*. Note: increasing salinity (red) is slightly obscured by control (green).

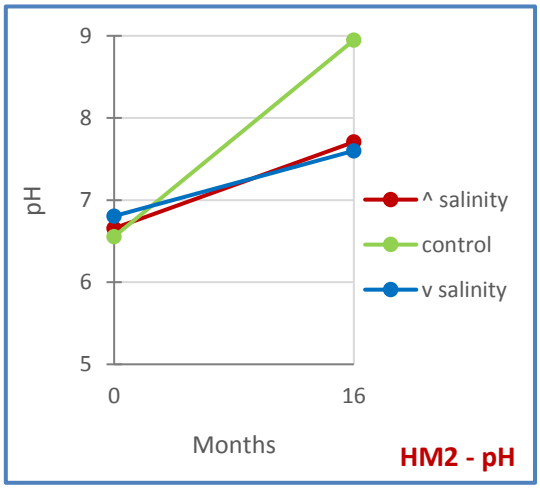


Figure 7.52: Community HM, plot HM2, pH, species *Disphyma crassifolium*.

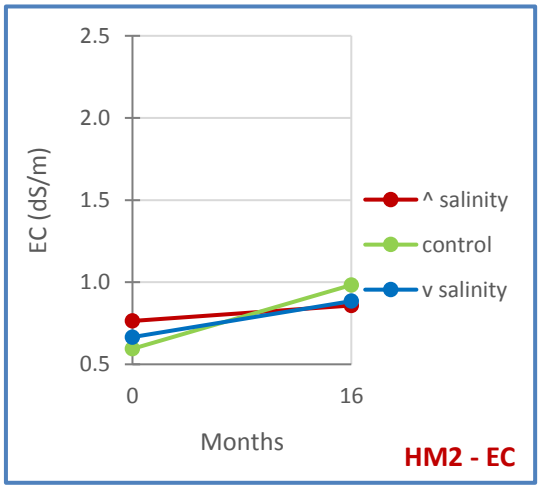


Figure 7.53: Community HM, plot HM2, EC, species *Disphyma crassifolium*.

Although pH levels of *D. crassifolium* in increasing salinity and decreasing salinity plots rose in the order of approximately one pH unit over the term of the study, pH levels in control significantly increased by over two units in each plot. This contrasted with the pH value of soils where they generally remained static. EC levels for both increasing salinity and control increased in both plots, possibly in response to increase in EC of soils. EC values in decreasing salinity fell in HM1, yet increased in HM2, while soil EC levels fell in both plots.

Sarcocornia blackiana

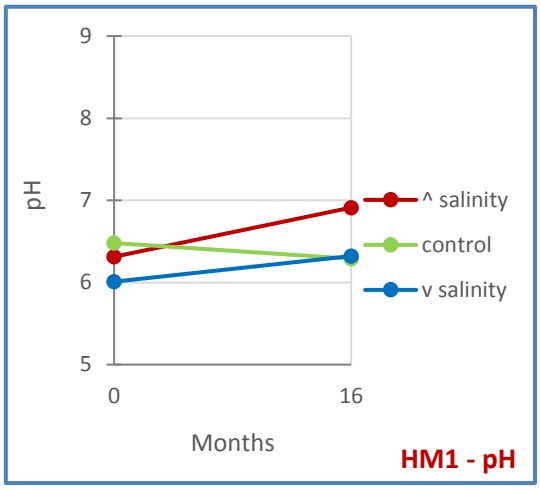


Figure 7.54: Community HM, plot HM1, pH, species *Sarcocornia blackiana*.

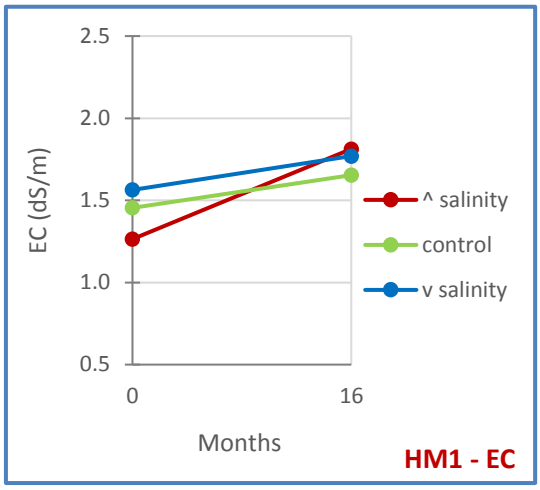


Figure 7.55: Community HM, plot HM1, EC, species *Sarcocornia blackiana*.

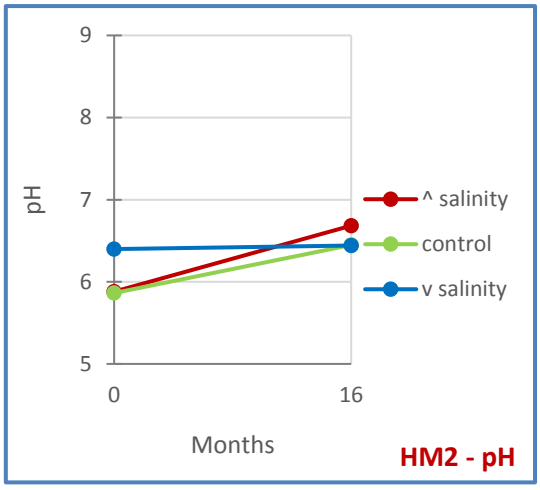


Figure 7.56: Community HM, plot HM2, pH, species *Sarcocornia blackiana*.

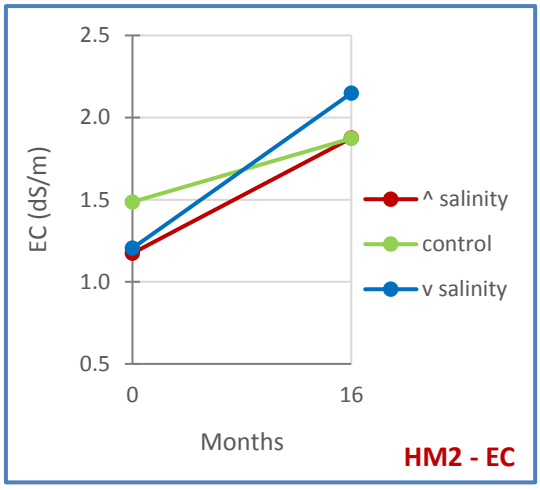


Figure 7.57: Community HM, plot HM2, EC, species *Sarcocornia blackiana*.

The pH levels for S. *blackiana* in both increasing salinity plots rose, control pH fell in HM1, and rose in HM2, while the reverse applied in decreasing salinity. EC values of all treatments recorded an increase with the greatest rise in decreasing salinity in HM2, this was unexpected. EC plant species observations did not reflect soil EC data, where there was a slight rise in increasing salinity, a fall in decreasing salinity and a large rise in control.

Sarcocornia quinqueflora

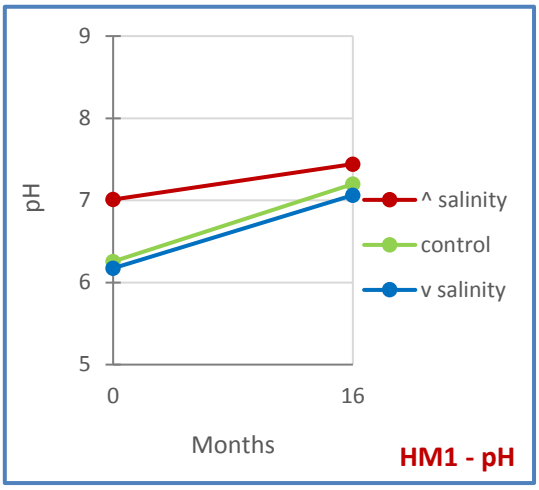


Figure 7.58: Community HM, plot HM1, pH, species *Sarcocornia quinqueflora*.

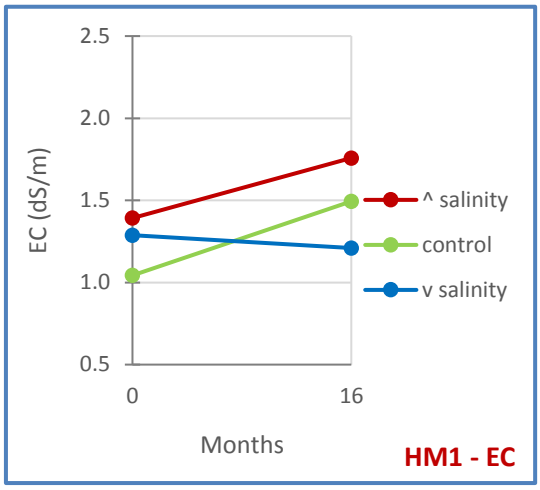


Figure 7.59: Community HM, plot HM1, EC, species *Sarcocornia quinqueflora*.

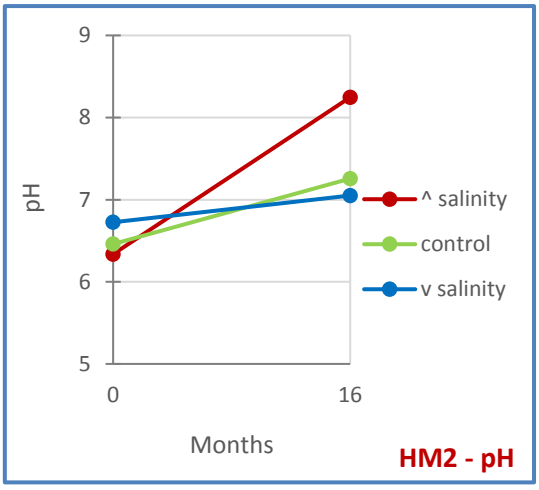


Figure 7.60: Community HM, plot HM2, pH, species *Sarcocornia quinqueflora*.

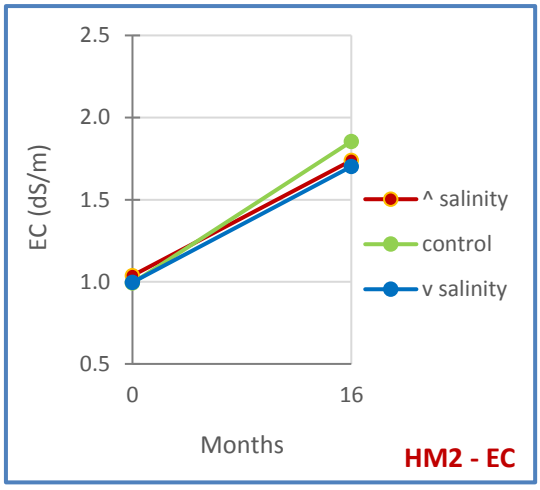


Figure 7.61: Community HM, plot HM2, EC, species *Sarcocornia quinqueflora*.

Similar to *D. crassifolium* (see page 7.25), *S. quinqueflora* recorded an increase in pH for all treatments in both plots with increasing salinity recording a rise of two full pH units in HM2. Again, this does not reflect that recorded in soil observations. EC values rose for *S. quinqueflora* in both increasing salinity and control, yet results were mixed in decreasing salinity plots where a decrease was observed in HM1, while an increase was recorded in HM2. The EC value increases for increasing salinity and control are generally a reflection of that observed in the soil data, however, the mixed results recorded in decreasing salinity display ambiguity.

Community TA (Tecticornia arbuscula)

There were four plant species present in this community, *D. crassifolium, S. blackiana, S. quinqueflora* and *T. arbuscula.*

Disphyma crassifolium

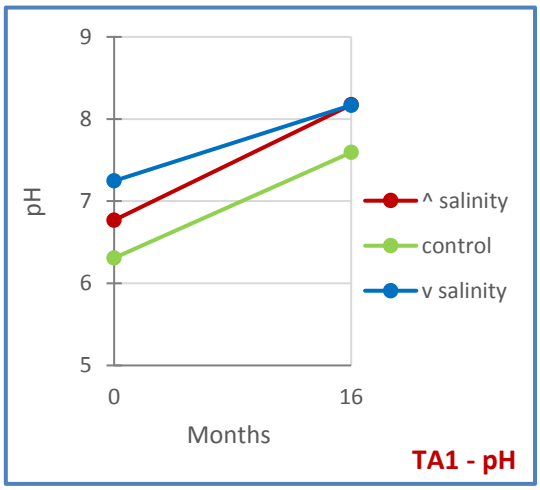


Figure 7.62: Community TA, plot TA1, pH, species *Disphyma crassifolium*.

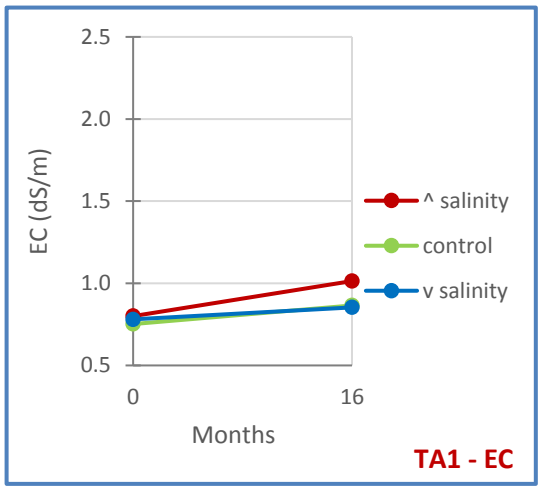


Figure 7.63: Community TA, plot TA1, EC, species *Disphyma crassifolium*. Note: control (green) is slightly obscured by decreasing salinity (blue).

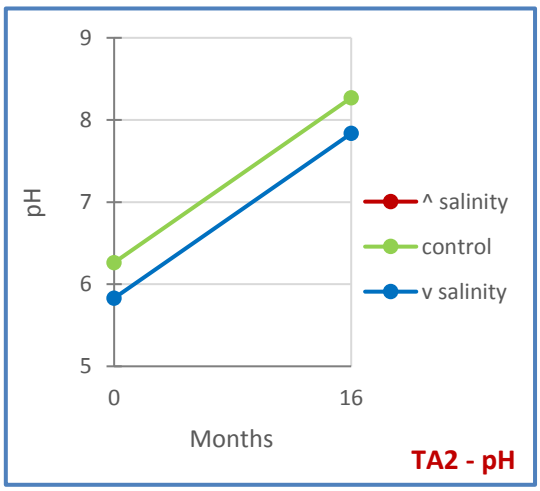


Figure 7.64: Community TA, plot TA2, pH, species *Disphyma crassifolium*. Note: not present in increasing salinity plot.

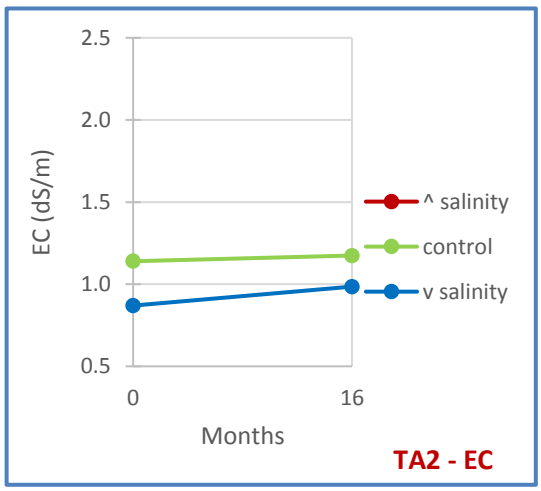


Figure 7.65: Community TA, plot TA2, EC, species *Disphyma crassifolium*. Note: not present in increasing salinity plot.

All pH values rose in all plots (species not found in increasing salinity in TA2), this contrary to pH values in soils where observations remained virtually unchanged. EC observations rose ever so slightly, however, start and end values were not consistent between plots TA1 and TA2. Differences are marked when compared to EC measurements for soils; increasing salinity values remained static, control mean rose two-fold, while decreasing salinity EC value fell.

Sarcocornia blackiana

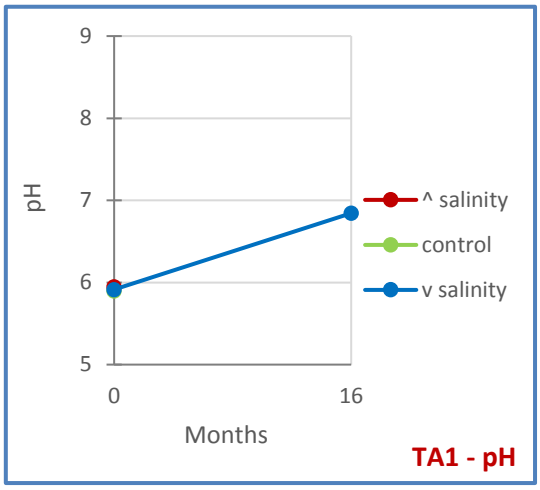


Figure 7.66: Community TA, plot TA1, pH, species *Sarcocornia blackiana*. Note: not observed in increasing salinity and control plots at end. Control (at start) obscured by decreasing salinity.

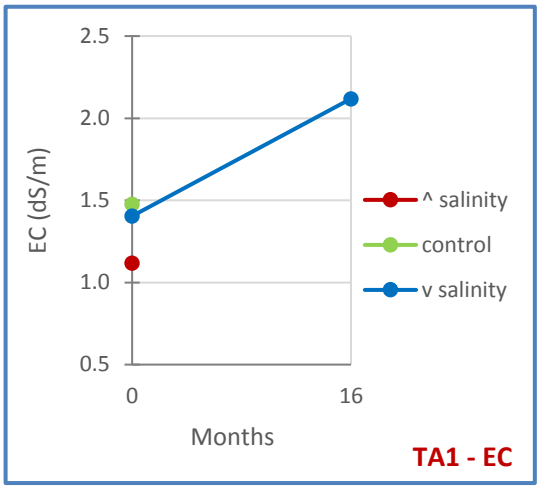


Figure 7.67: Community TA, plot TA1, EC, species *Sarcocornia blackiana*. Note: not observed in increasing salinity and control plots at end.

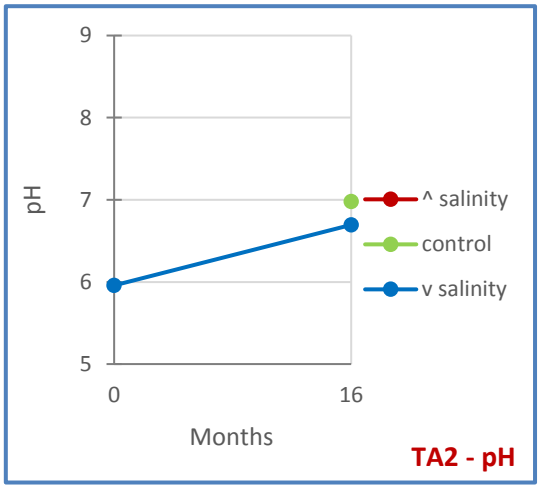


Figure 7.68: Community TA, plot TA2, pH, species *Sarcocornia blackiana*. Note not found in increasing salinity plot; not observed in control at start.

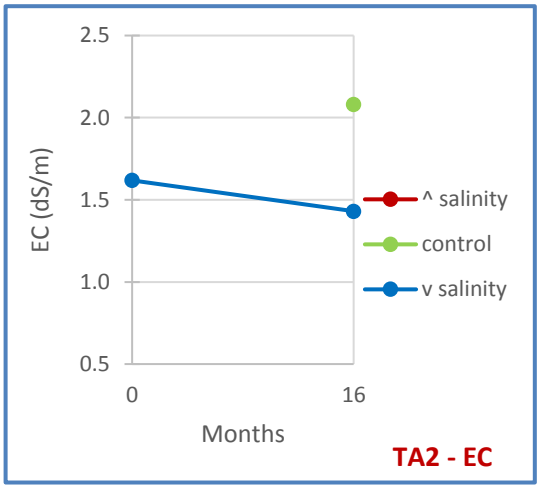


Figure 7.69: Community TA, plot TA2, EC, species *Sarcocornia blackiana*. Note not found in increasing salinity plot; not observed in control at start.

Here, commentary is restricted to decreasing salinity as *S. blackiana* was not present in increasing salinity plot TA2, not observed in increasing salinity and control plot TA1 plots at end, and not observed in control TA2 plot at start. Note: failure to observe plant species at conclusion does not suggest species death during study. Values for pH rose nearly one pH unit, while little change reported in soil pH levels. Plot TA1 decreasing salinity showed a strong increase in EC (contrary to expectations), while plot TA2, showed a smaller decrease (met expectations). Soil EC levels in decreasing salinity displayed a decline.

Sarcocornia quinqueflora

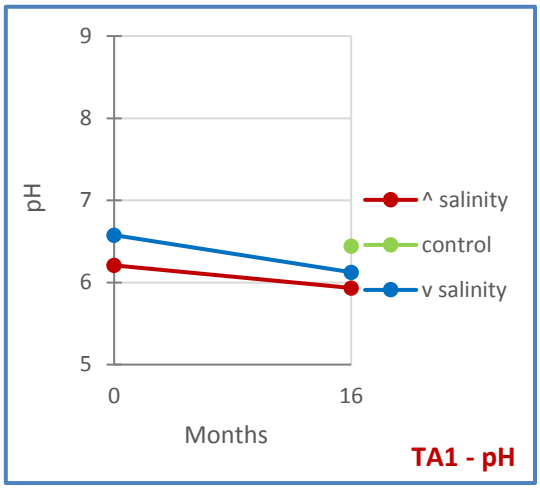


Figure 7.70: Community TA, plot TA1, pH, species *Sarcocornia quinqueflora*. Note: not observed in control plot at start.

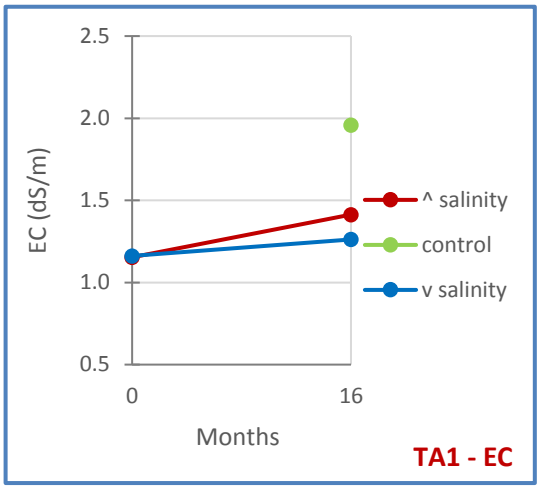


Figure 7.71: Community TA, plot TA1, EC, species *Sarcocornia quinqueflora*. Note: not observed in control plot at start.

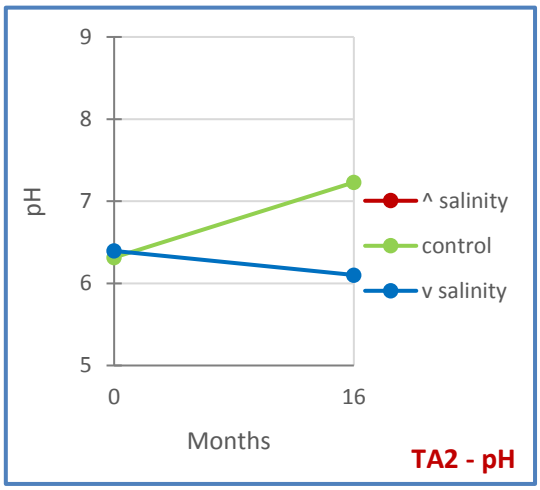


Figure 7.72: Community TA, plot TA2, pH, species *Sarcocornia quinqueflora*. Note: not present in increasing salinity plot.

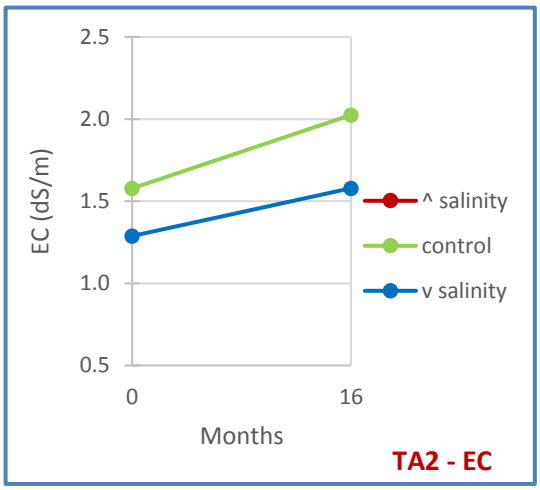


Figure 7.73: Community TA, plot TA2, EC, species *Sarcocornia quinqueflora*. Note: not present in increasing salinity plot.

Comments are somewhat restricted as *S. quinqueflora* was not observed at commencement in TA1 control plot, and not present in the TA2 increasing salinity plot. Levels of pH fell for increasing salinity in TA1, and decreasing salinity in TA1 and TA2 plots, while it rose in control (TA2), yet soil pH values were generally static. All EC values rose in all plots in which *S. quinqueflora* was present, however, this did not reflect soil EC values, where increasing salinity was static, control rose sharply and decreasing salinity EC values declined.

Tecticornia arbuscula

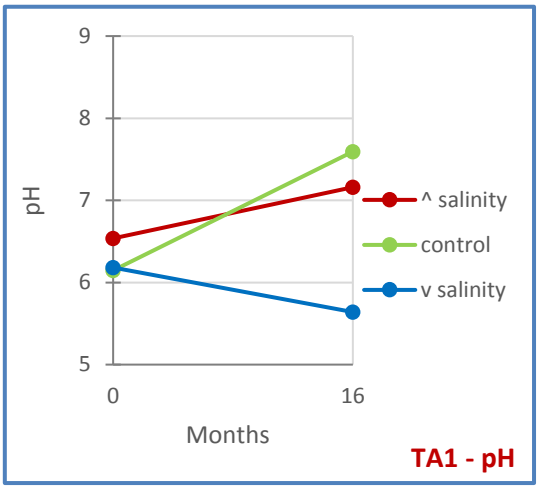


Figure 7.74: Community TA, plot TA1, pH, species *Tecticornia arbuscula*.

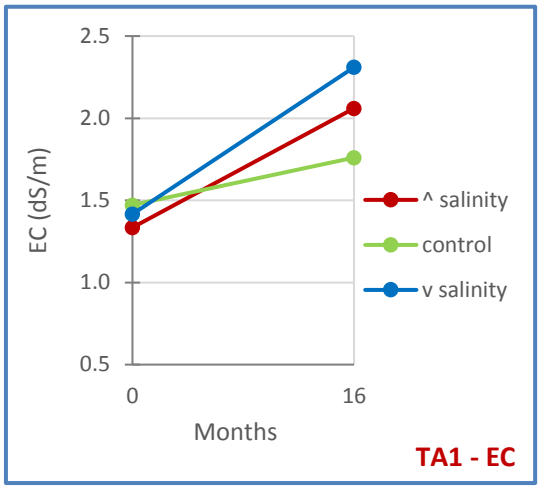


Figure 7.75: Community TA, plot TA1, EC, species *Tecticornia arbuscula*.

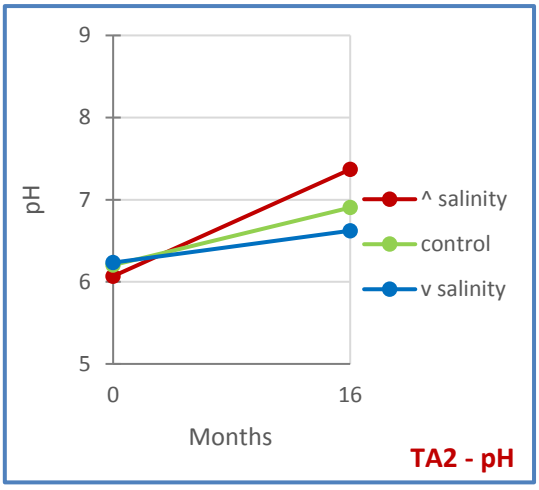


Figure 7.76: Community TA, plot TA2, pH, species *Tecticornia arbuscula*.

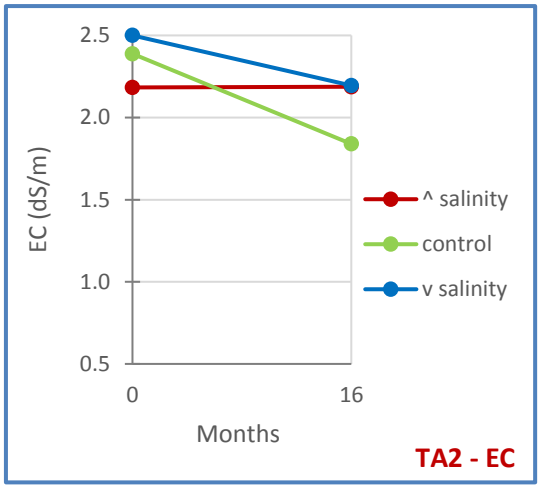


Figure 7.77: Community TA, plot TA2, EC, species *Tecticornia arbuscula*.

Increasing salinity and control plots recorded a rise in pH values for *T. arbuscula*, while in decreasing salinity plots mixed results (a rise and a fall) were observed. This contrasts with soil pH values where all plots recorded virtually no change. EC observations produced startling contradictory results where in TA1 all plots recorded increases, yet TA2 plots, except for increasing salinity, EC values fell. Again, a match to soil EC observations was inconsistent where increasing salinity recorded no change, control a large rise and decreasing salinity a fall. Interestingly, although starting EC observation values were very different in both plots, conclusion values were nearly identical, particularly in relation to control and decreasing salinity. It is unclear why this occurred; perhaps the addition of marine and fresh water provided a degree of stability to the ground-water system, however this does not account for end outcome in control plots.

Community GL (grass lands)

There were three plant species present in this community, *D. crassifolium, S. blackiana* and *S. quinqueflora.*

Disphyma crassifolium

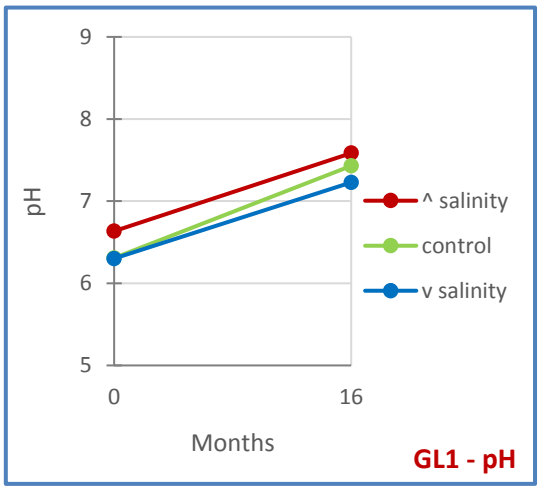


Figure 7.78: Community GL, plot GL1, pH, species *Disphyma crassifolium*.

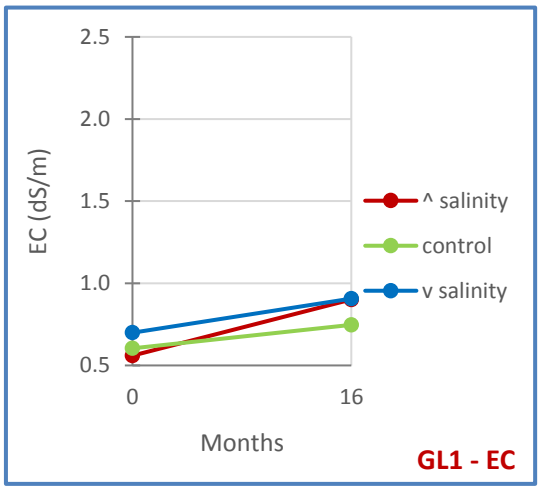


Figure 7.79: Community GL, plot GL1, EC, species *Disphyma crassifolium*.

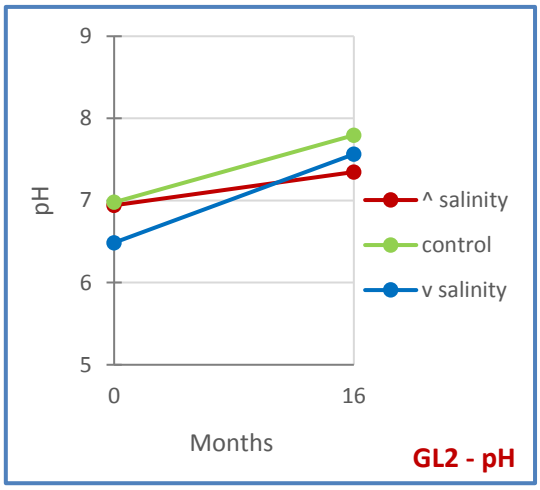


Figure 7.80: Community GL, plot GL2, pH, species *Disphyma crassifolium*.

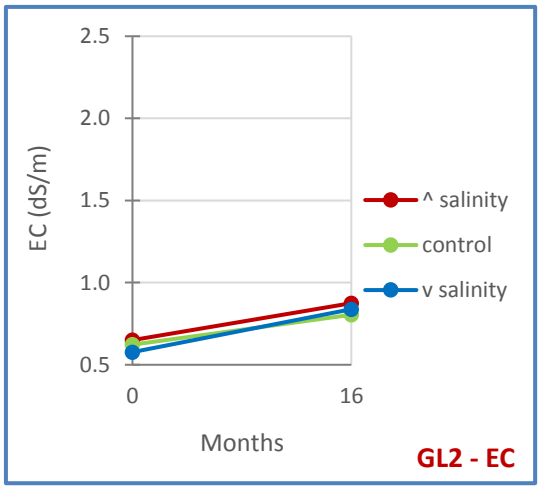


Figure 7.81: Community GL, plot GL2, EC, species *Disphyma crassifolium*.

Although soil pH levels in all plots were mainly static throughout the study, pH levels for *D. crassifolium* all rose, several a full pH unit (all in GL1 and decreasing salinity in GL2). EC values for all treatments in both plots showed an increase. The increase appears small; however, all began from a low base. The rate of EC increase for *D. crassifolium* is similar to that in other vegetation communities.

Sarcocornia blackiana

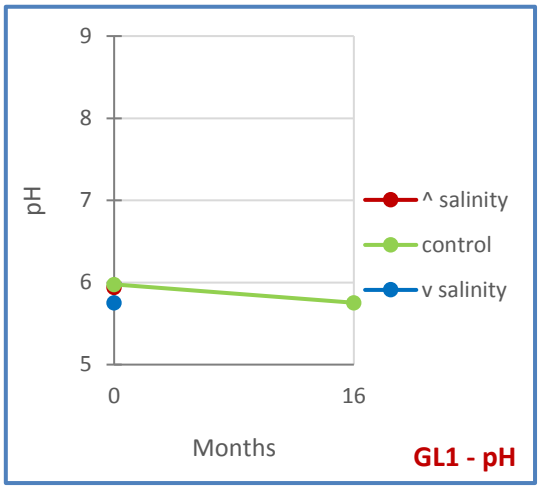


Figure 7.82: Community GL, plot GL1, pH, species *Sarcocornia blackiana*. Note: not observed in increasing/decreasing salinity plots at conclusion of study.

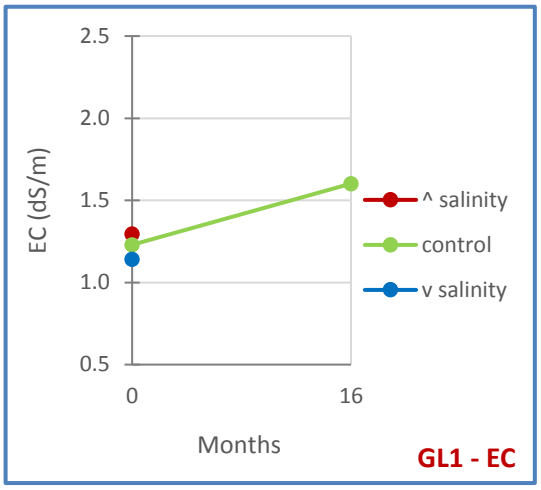


Figure 7.83: Community GL, plot GL1, EC, species *Sarcocornia blackiana*. Note: not observed in increasing/decreasing salinity plots at conclusion of study.

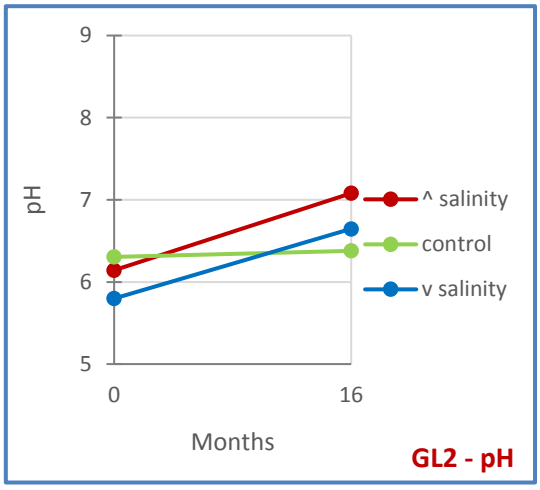


Figure 7.84: Community GL, plot GL2, pH, species *Sarcocornia blackiana*.

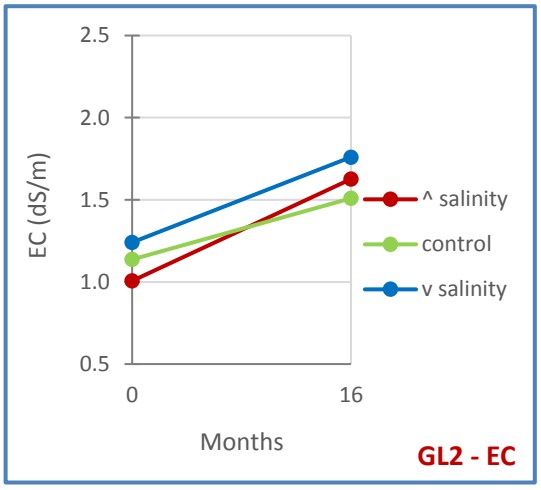


Figure 7.85: Community GL, plot GL2, EC, species *Sarcocornia blackiana*.

The pH values for increasing and decreasing salinities both rose in GL2 (recorded at commencement in GL1, however not observed at conclusion; death is not suspected). Control pH values either fell slightly (GL1) or remained static (GL2). It is noted that pH values of GL plot soils generally remained static over the course of the study. Rises in EC were observed for control (GL1) and across all treatments in GL2. However, this is not a reflection of soil EC observations where increasing salinity and control rose very little and a small fall was observed in decreasing salinity.

Sarcocornia quinqueflora

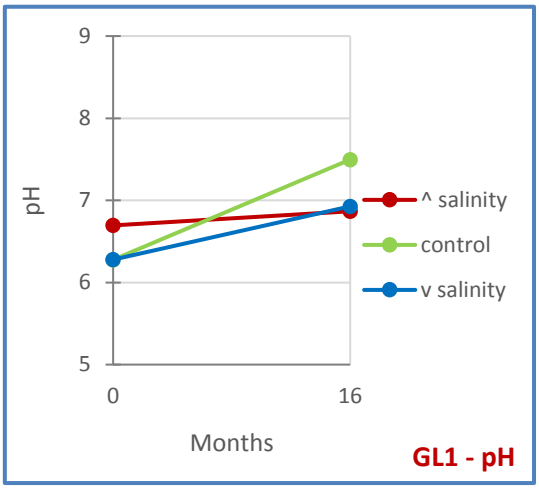


Figure 7.86: Community GL, plot GL1, pH, species *Sarcocornia quinqueflora*.

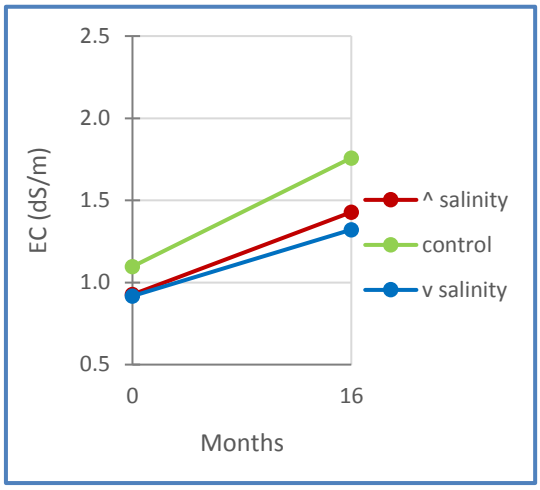


Figure 7.87: Community GL, plot GL1, EC, species *Sarcocornia quinqueflora*.

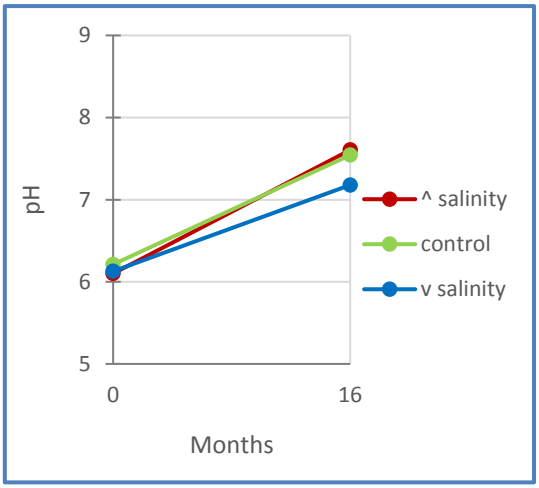


Figure 7.88: Community GL, plot GL2, pH, species *Sarcocornia quinqueflora*.

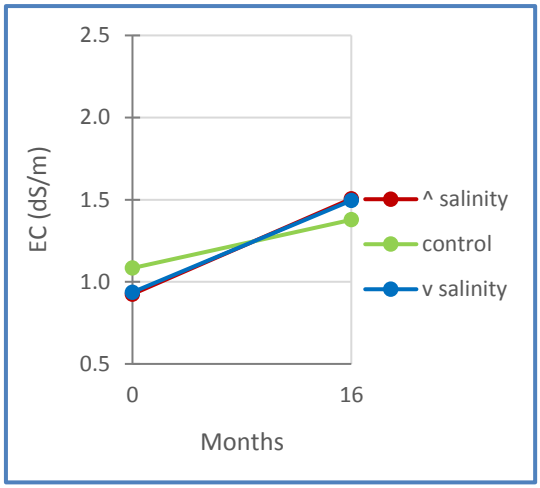


Figure 7.89: Community GL, plot GL2, EC, species *Sarcocornia quinqueflora*. Note: increasing salinity (red) is obscured by decreasing salinity (blue).

All *S. quinqueflora* pH values rose, although the pH rise in increasing salinity in GL1 was very moderate. This contrasts with soil pH observations where they were generally static. Similarly, all EC values rose, again, contrasting soil observations where EC values remained constant throughout the study period.

7.4.6 Summary – plant species

pH

Across all plant species assessed in this study variations between start and end pH observations by treatment were recorded (Table 7.4).

Table 7.4: Commencement and conclusion pH values by treatment. Means and standard error. Positive t-test values indicate conclusion pH values are lower than commencement pH values; negative values indicate conclusion pH values are higher than commencement pH values.

Plant species	Treatment	Commencement pH	Conclusion pH	% change	t-test	p-value
Disphyma crassifolium	Increasing salinity	6.66 ± 0.072	7.62 ± 0.105	14.41	-5.043	0.0005
	Control	6.43 ± 0.082	8.13 ± 0.174	26.44	-5.986	0.0001
	Decreasing salinity	6.56 ± 0.132	7.73 ± 0.092	17.84	-4.915	0.0003
Sarcocornia blackiana	Increasing salinity	6.04 ± 0.056	6.89 ± 0.073	14.07	-8.279	0.0000
	Control	6.09 ± 0.079	6.37 ± 0.130	4.60	-1.153	0.1412
	Decreasing salinity	5.94 ± 0.072	6.59 ± 0.062	10.94	-5.116	0.0002
Sarcocornia quinqueflora	Increasing salinity	6.55 ± 0.098	7.25 ± 0.183	10.69	-2.283	0.0207
	Control	6.38 ± 0.050	7.19 ± 0.083	12.70	-5.880	0.0000
	Decreasing salinity	6.38 ± 0.054	6.93 ± 0.137	8.62	-2.569	0.0111
Tecticornia arbuscula	Increasing salinity	6.30 ± 0.135	7.26 ± 0.060	15.24	-3.752	0.0321
	Control	6.18 ± 0.019	7.04 ± 0.082	13.92	-6.050	0.0131
	Decreasing salinity	6.21 ± 0.017	6.13 ± 0.283	-1.29	0.156	0.4452

In all, except for *T. arbuscula*, pH had risen by the conclusion of the study, with nearly all changes being significant ($p<0.05$). Increases ranged from 8.62 ($p=0.0111$) to 26.44% ($p=0.0001$) with the most consistent rise occurring under increasing salinity (range 10.69-15.24%). The most variable increase was observed in the control plots (range 4.60-26.44%), followed by decreasing salinity (range 1.29-17.84%), with increasing salinity recording the least change. The only fall in pH value was detected in *T. arbuscula* occurring in decreasing salinity (fall of 1.29%), this being insignificant ($p=0.4452$). Observations on a plant species basis shows that *T. arbuscula* experienced the greatest pH changes of the four species (-1.29 to 15.32%, p-values 0.0131 to 0.4452), followed by significant pH changes in *D. crassifolium* (14.41 to 26.44%, p-values 0.0001 to 0.0005), while *S. quinqueflora* had the least change (8.62 to 12.70%), yet increasing and decreasing salinities were significant (p-values 0.0207 and 0.0111 respectively). In terms of pH tolerance, *T. arbuscula* experienced the lowest mean value (6.13 ± 0.283), while *D. crassifolium* was associated with the highest mean pH (8.13 ± 0.174).

EC

Variations between start and end EC observations by treatment were also recorded across all plant species but at a higher rate than that of pH (Table 7.5).

Table 7.5: Commencement and conclusion EC values by treatment. Means and standard error. Positive t-test values indicate conclusion EC values are lower than commencement EC values; negative values indicate conclusion EC values are higher than commencement EC values.

Plant species	Treatment	Commencement EC	Conclusion EC	% change	t-test	p-value
Disphyma crassifolium	Increasing salinity	0.69 ± 0.029	0.90 ± 0.020	30.43	-3.946	0.0021
	Control	0.73 ± 0.058	0.91 ± 0.042	24.66	-1.717	0.0584
	Decreasing salinity	0.77 ± 0.043	0.88 ± 0.018	14.29	-1.592	0.0712
Sarcocornia blackiana	Increasing salinity	1.19 ± 0.039	1.77 ± 0.047	48.74	-9.059	0.0000
	Control	1.38 ± 0.062	1.74 ± 0.069	26.09	-3.063	0.0078
	Decreasing salinity	1.36 ± 0.048	1.85 ± 0.088	36.03	-3.584	0.0025
Sarcocornia quinqueflora	Increasing salinity	1.16 ± 0.051	1.59 ± 0.037	37.07	-4.728	0.0002
	Control	1.16 ± 0.052	1.79 ± 0.056	54.31	-5.962	0.0000
	Decreasing salinity	1.11 ± 0.036	1.46 ± 0.042	31.53	-4.359	0.0003
Tecticornia arbuscula	Increasing salinity	1.76 ± 0.245	2.12 ± 0.038	20.45	-0.849	0.2427
	Control	1.93 ± 0.265	1.80 ± 0.025	-6.74	0.279	0.4031
	Decreasing salinity	1.97 ± 0.321	2.25 ± 0.033	14.21	-0.503	0.3325

Again, in all except for one instance, EC values increased, most rose substantially, many significantly. Increases ranged from 14.21 to 54.31% with the most consistent increase occurring in decreasing salinity (range 14.21-36.03%, spread ~22%), the greatest rise evident in control (range 24.66-54.31%, spread 29%) closely followed by increasing salinity (range 20.45-48.74%, spread 28%). The only instance of EC decline was recorded by *T. arbuscula* in control treatment (fall of 6.74%).

Observations on a plant species basis shows that *S. quinqueflora* recorded significant changes in EC of the four species (range 31.53-54.31%, spread ~23%, p-values 0.0000-0.0003), closely followed by it congenor species *S. blackiana* (range 26.09-48.74%, spread ~22%, p-values 0.000-0.0078), while *T. arbuscula* recorded the least, yet, insignificant change (range 6.74-20.45%, spread ~14%, p-values 0.2427-0.4031). *D. crassifolium* exhibited the lowest values of EC (0.69-0.91) while *T. arbuscula* had the highest EC observations (1.76-2.25).

7.4.7 Summary – soil and plant species

pH

Individual plant species means, and minimum and maximum of commencement and conclusion soil pH values by plant species are presented in Table 7.6.

Table 7.6: Soil commencement and conclusion pH values by plant species. Means and standard error. Positive t-test values indicate conclusion pH values are lower than commencement pH values; negative values indicate conclusion pH values are higher than commencement pH values.

	Commencement pH			Conclusion pH				
Plant species	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**t-test**	**p-value**
Disphyma crassifolium	5.45 ± 0.170	4.71	6.84	5.41 ± 0.162	4.73	6.68	0.148	0.4417
Sarcocornia blackiana	5.40 ± 0.172	4.71	6.84	5.37 ± 0.166	4.73	6.68	0.123	0.4515
Sarcocornia quinqueflora	5.66 ± 0.153	4.71	6.84	5.55 ± 0.138	4.73	6.67	0.487	0.3145
Tecticornia arbuscula	6.32 ± 0.168	5.95	6.84	6.36 ± 0.088	6.14	6.68	-0.272	0.3955

Little change to soil pH mean by plant species was observed during the study period, this supported by t-test results where no species reported significant difference between pH commencement and conclusion means. At the study's beginning, plant species, *D. crassifolium* (soil commencement pH mean 5.45 ± 0.170), *S. blackiana* (mean 5.40 ± 0.172) and *S. quinqueflora* (mean 5.66 ± 0.153) experienced a greater than two pH units variation in soil pH (range 4.71 to 6.84), while *T. arbuscula* (soil commencement pH mean 6.32 ± 0.168) appeared in a more constricted range of less than one pH unit (range 5.95 to 6.84). Ignoring the small decrease in pH for *T. arbuscula* in decreasing salinity (-1.29%, Table 7.4, page 7.35), it is unclear why plant pH values increased ranging 4.6% (*S. blackiana*, control) to 26.4% (*D. crassifolium*, control), yet, soil pH observations remained static. The minimum and maximum values for *D. crassifolium*, *S. blackiana* and *S. quinqueflora* are all similar as each was a member of the HM community which recorded the lowest minimum and highest maximum pH values. Although the three species were also found in the TA community, that community's pH values were more restrained, hence the presence of *T. arbuscula* in the TA community and not the HM community as its pH tolerance range is far less than the other species. At the end of the study, soil pH means by plant species remained static, while a small change to the spread of pH values was observed. The maximum pH values for *D. crassifolium*, *S. blackiana* and *S. quinqueflora* was reduced (6.84 to 6.68), while

for *T. arbuscula* both minimum and maximum pH values were altered contracting the range of pH from 0.89 to 0.54.

EC

Individual plant species means, and minimum and maximum of commencement and conclusion soil EC values by plant species are presented in Table 7.7.

Table 7.7: Soil commencement and conclusion EC values by plant species. Means and standard error. Positive t-test values indicate conclusion EC values are lower than commencement EC values; negative values indicate conclusion EC values are higher than commencement EC values.

	Commencement EC			Conclusion EC				
Plant species	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**t-test**	**p-value**
Disphyma crassifolium	14.14 ± 2.016	4.41	32.88	15.81 ± 2.449	1.82	39.74	-0.527	0.3010
Sarcocornia blackiana	13.91 ± 2.243	4.41	32.88	14.32 ± 2.522	1.82	39.74	-0.121	0.4522
Sarcocornia quinqueflora	15.46 ± 1.569	4.41	32.88	16.56 ± 1.880	1.82	39.74	-0.451	0.3272
Tecticornia arbuscula	22.87 ± 2.878	11.18	32.88	26.11 ± 3.195	16.81	39.74	-0.753	0.2344

Again, a small change to soil EC means by plant species was observed during the study period, the result supported by the t-test analysis where there is no significant difference between EC commencement and conclusion means. At the study's beginning, *D. crassifolium* (soil commencement EC mean 14.14 ± 2.016), *S. blackiana* (mean 13.91 ± 2.243) and *S. quinqueflora* (mean 15.46 ± 1.569) experienced an eight-fold variation in soil EC values (4.41 to 32.88), while *T. arbuscula* (soil commencement mean 22.87 ± 2.878) appeared in a narrower three-fold range in soil EC (11.18 to 32.88). At the end of the study, soil EC means by plant species remained static for *D. crassifolium*, *S. blackiana* and *S. quinqueflora*, while an increase for *T. arbuscula* (soil conclusion EC mean 26.11 ± 3.195) was observed. In respect to soil EC observations range by plant species, *D. crassifolium*, *S. blackiana* and *S. quinqueflora,* all increased (from 28.47 to 37.92), while *T. arbuscula* both minimum and maximum EC values increased, shifting the range of EC but maintaining the spread (21.70 to 22.93). Similar to plant/soil pH variations, it is unclear to why soil EC observations remained generally static, yet plant EC values increased substantially between 14.2 and 54.3%.

7.5 Conclusions

This work was a short, experimental field-based study into prospective changes to selected plants and soils of coastal Tasmanian saltmarshes in response to potential sea-level rise and climate change impacts.

Mean soil pH values by treatment showed little change over the course of the study, suggesting strong environmental buffering. However, changes in soil EC observations were apparent across each treatment with control plots displaying the greatest variation. A possible cause is that maintaining greater moisture (wetness) in treatment plots countered the natural evaporation experienced by the control plots, which in turn led to higher salt levels in the upper soil.

Mean pH values by plant species did change following application of marine/fresh water and also changed in control plots. Each species recorded various levels of pH change, ranging 1.3% (*T. arbuscula*, decreasing salinity) to 17.8% (*D. crassifolium*, decreasing salinity). Changes in plant species EC values outstripped that observed in pH. The smallest change recorded was 14.3% (*D. crassifolium*, decreasing salinity), while the greatest change observed was 48.7% (*S. blackiana*, increasing salinity). If control plots were considered, the degree of change would be greater (6.7%, *T. arbuscula*, to 54.3%, *S. quinqueflora*).

Generally, changes in plant species pH were not a close reflection of soil pH observations. In most cases plant pH increased substantially to that of soil pH, which were more constant. Similar changes in observations were recorded for EC values irrespective of increasing/decreasing salinity or control, although EC levels in all plant species was far less than that of soils. This is likely a reflection of each plant species' differing salt physiology; however, this was not measured as it fell outside scope of this study.

Observations from this short-term study shows that the four plant species of interest would be likely to survive both increasing and decreasing salinity trends, with little to no change in vegetation composition within their respective communities. However, this comes with a caveat. This was a short-term study, only running for 16 months (with a four month gap). Longer term implications of increasing and decreasing salinity impacts to individual plant species are unknown at this stage. Results also showed that

changes to soil conditions are limited, particularly in respect to pH. Changes to EC levels were noted, however, when control plots are excluded, changes to both increasing salinity and decreasing salinity EC values were not excessive.

Further research

This small study has identified the need for more work at a far larger scale to better understand the impacts of increasing and decreasing salinity on coastal saltmarsh plants. It would be prudent to extend the study length to at least three years as this would better clarify plant species survivability to changing regimes of marine and fresh water over time. Additional species should also be integrated into the study, especially from the upper saltmarsh zone, those species (particularly graminoids, e.g. *A. stipoides, Gahnia filum*) rarely subject to tidal inundation. Consideration also should be given to include other key species such as *Juncus kraussii, Samolus repens* and *Selliera radicans*, which occupy several vegetation communities as well as being present state-wide. Lastly, it would be advisable to conduct the study across multiple sites as this would take into consideration any modifying influences of climatic variation (rainfall, solar exposure), soil variation (sand, peat) and aspect (east coast, south coast).

7.6 Acknowledgements

Many thanks to the Tasmanian Land Conservancy (TLC) for use of their reserve at Long Point as the research site for this adjunct study. Thanks also to Denna Kingdom (TLC Reserves Manager) for arranging ongoing access to Long Point and to Mick Graham (Farm Manager) for continuous access through The Grange. This project could not have been successfully completed without the assistance of Ross Lucas, who, each fortnight over the course of the project, assisted in the collection of saltwater and the carrying of thirty-six 25 litre drums filled with water to various plots. Thanks also to Stuart Macdonald, David Green and Peter McQuillan who assisted at times Ross was away. Over 27 waterings, we carried 972 twenty-five litre drums filled with water (24,300 kilograms of water). It was hard work!

7.7 References

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7.8 Appendix

Commencement and conclusion photos of individual field-plots are presented in Figures 7A.1 to 7A.64.

The following is a series of photographs taken at the commencement and conclusion of this study. They are arranged by vegetation type, SQ (*Sarcocornia quinqueflora*), HM (herbs mixed), TA (*Tecticornia arbuscula*) and GL (grasslands). The vegetation types were selected to resemble vegetation communities ASQ, AHM, ASH and AGH, formulated and described in Chapter 3. Each section of photographs has a start and end set of the respective community (two of, as each is replicated), followed by start and end images of each treatment, increasing salinity, decreasing salinity and control. The start photographs were taken in December 2016, the end in April 2018. The end images appear to have a colour distortion, increasing red/yellow saturation, however, all images are of natural colour tones, none have been enhanced. All photographs were taken with the same camera, all on the same setting. The red saturation, particularly in *S. quinqueflora*, is a result of the visibility of leaf anthocyanin, which is an adaptation to highly saline and sunny environments (Kitchener & Harris 2013), this mainly evident during late summer and early autumn period. Anthocyanins can be a guide to the pH level of living plant matter as their colour alters with pH; for example, red or pink is an indicator of an acidic solution (pH <7). The end GL images (both GL1 and GL2) show what appears to be exceptional growth of *A. stipoides* (coast speargrass), particularly within increasing and decreasing salinity plots. This is possibly due to the constant watering (irrespective whether marine or fresh) over summer months which appeared to be beneficial to the plant. It is unclear to what degree the watering effected the graminoid, unfortunately, this plant species was not part of the study, in hindsight is should have been.

Figure 7A.1: SQ plots start, view northwest.

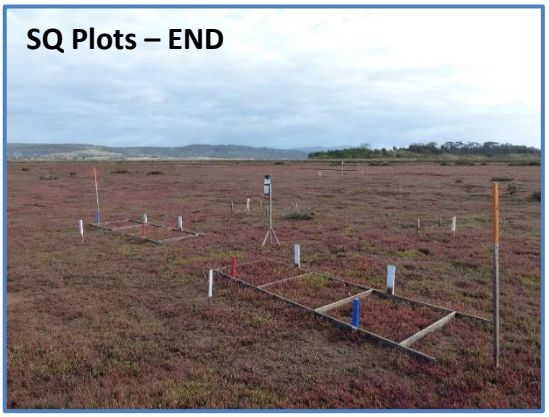

Figure 7A.2: SQ plots end, view northwest.

Figure 7A.3: SQ1 increasing salinity start.

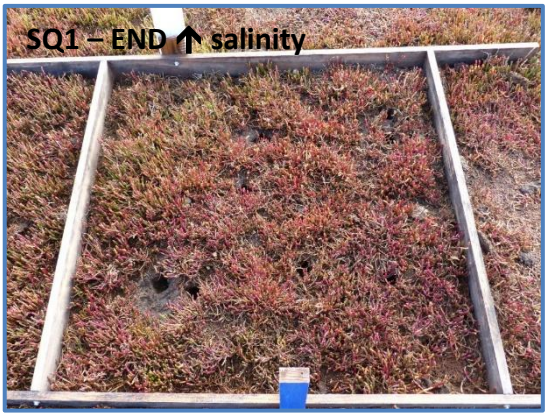

Figure 7A.4: SQ1 increasing salinity end.

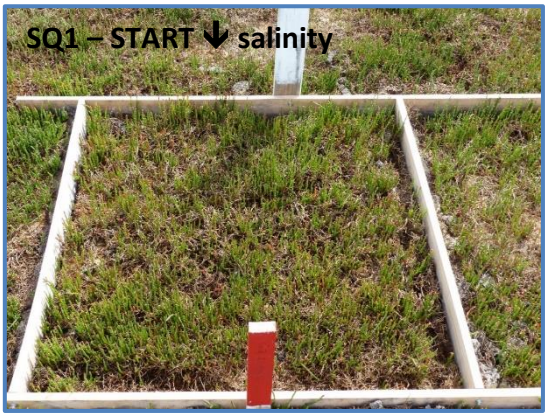

Figure 7A.5: SQ1 decreasing salinity start.

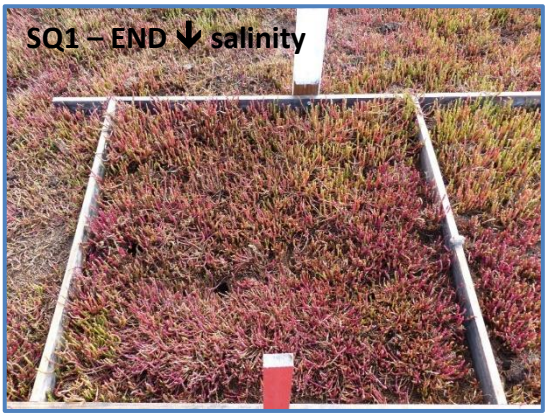

Figure 7A.6: SQ1 decreasing salinity end.

Figure 7A.7: SQ1 control start.

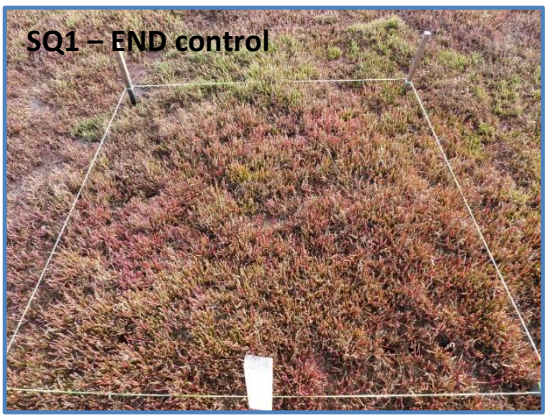

Figure 7A.8: SQ1 control end.

Figure 7A.9: SQ2 increasing salinity start.

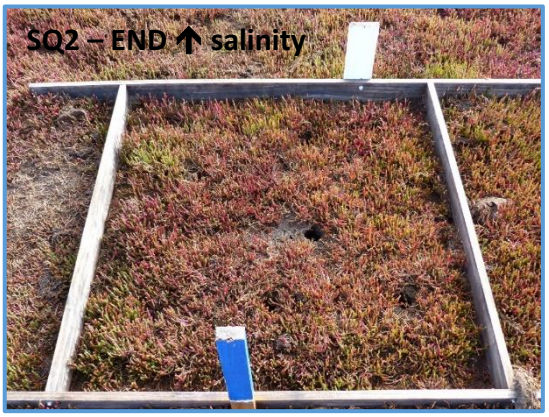

Figure 7A.10: SQ2 increasing salinity end.

Figure 7A.11: SQ2 decreasing salinity start.

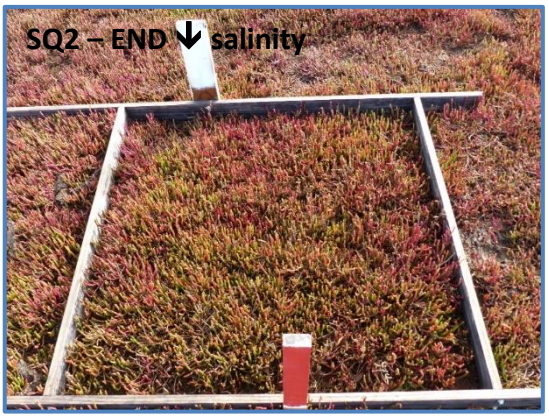

Figure 7A.12: SQ2 decreasing salinity end.

Figure 7A.13: SQ2 control start.

Figure 7A.14: SQ2 control end.

Figure 7A.15: SQ plots start, view southeast.

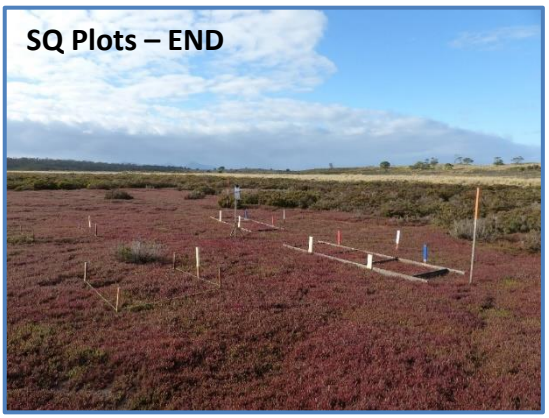

Figure 7A.16: SQ plots end, view southeast.

Figure 7A.17: HM plots start, view northwest.

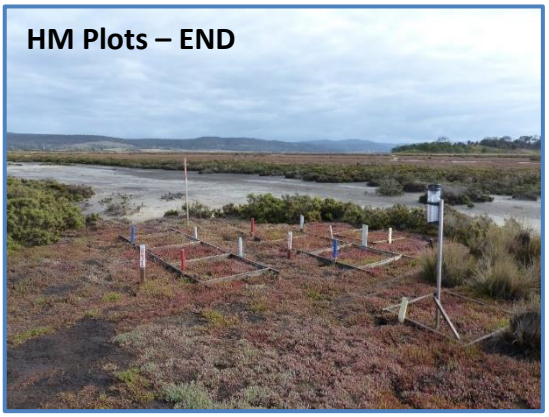

Figure 7A.18: HM plots end, view northwest.

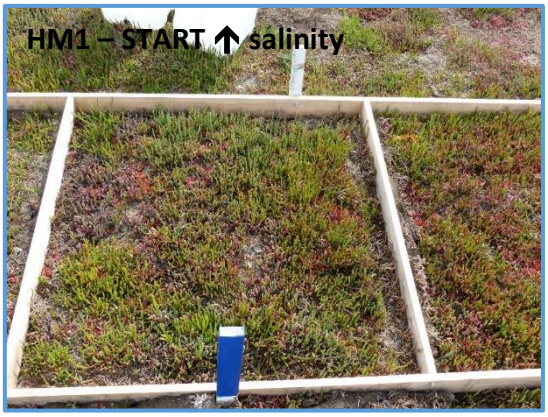

Figure 7A.19: HM1 increasing salinity start.

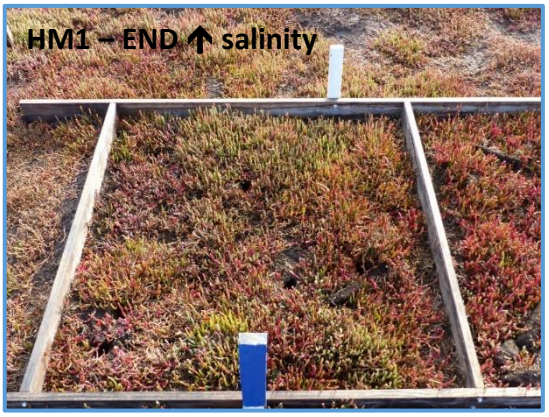

Figure 7A.20: HM1 increasing salinity end.

Figure 7A.21: HM1 decreasing salinity start.

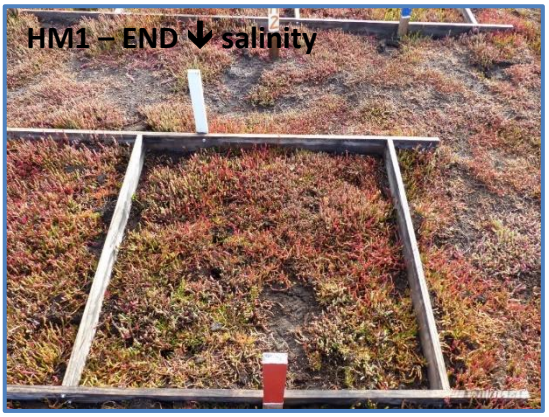

Figure 7A.22: HM1 decreasing salinity end.

Figure 7A.23: HM1 control start.

Figure 7A.24: HM1 control end.

Figure 7A.25: HM2 increasing salinity start.

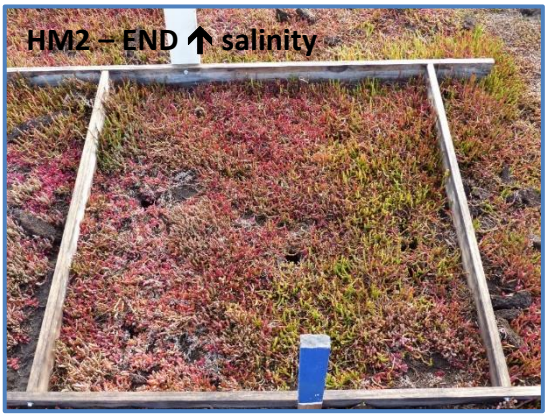

Figure 7A.26: HM2 increasing salinity end.

Figure 7A.27: HM2 decreasing salinity start.

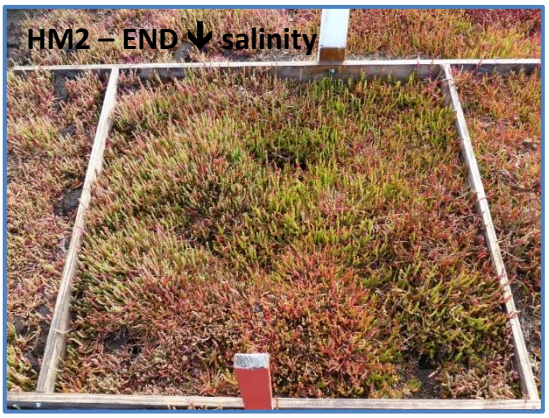

Figure 7A.28: HM2 decreasing salinity end.

Figure 7A.29: HM2 control start.

Figure 7A.30: HM2 control end.

Figure 7A.31: HM plots start, view southwest.

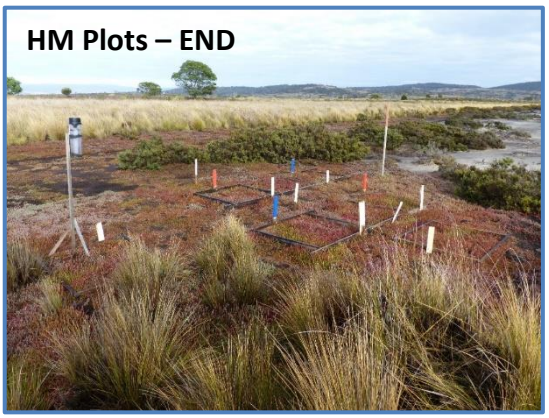

Figure 7A.32: HM plots end, view southwest.

Figure 7A.33: TA1 plots start, view northwest.

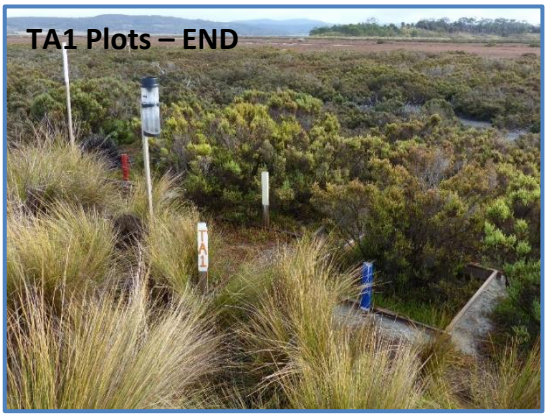

Figure 7A.34: TA1 plots end, view northwest.

Figure 7A.35: TA1 increasing salinity start.

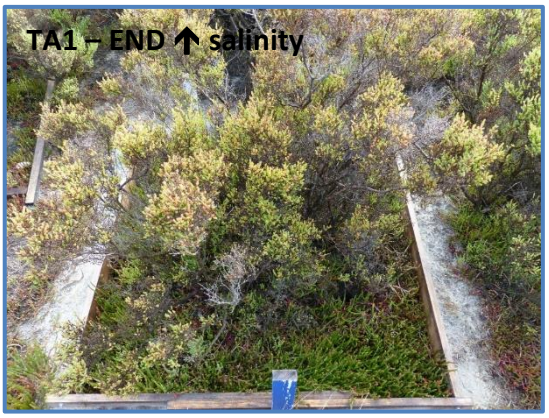

Figure 7A.36: TA1 increasing salinity end.

Figure 7A.37: TA1 decreasing salinity start.

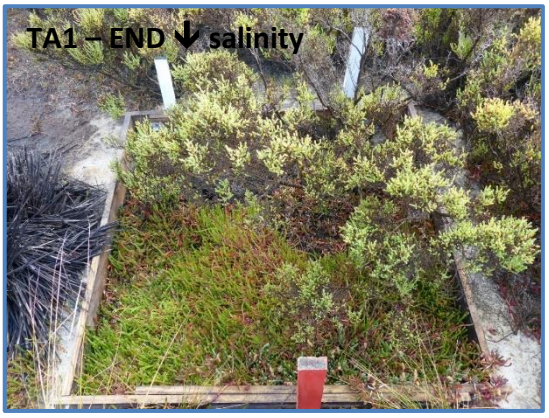

Figure 7A.38: TA1 decreasing salinity end.

Figure 7A.39: TA1 control start.

Figure 7A.40: TA1 control end.

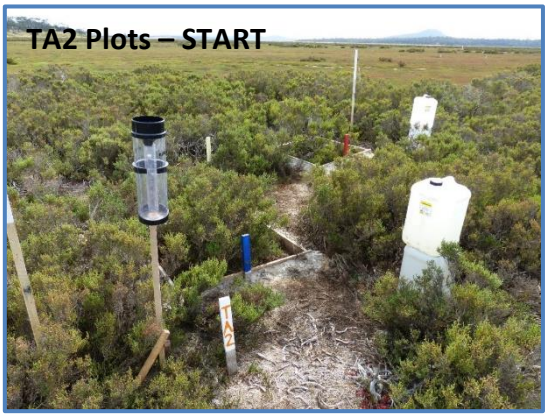

Figure 7A.41: TA2 plots start, view southwest.

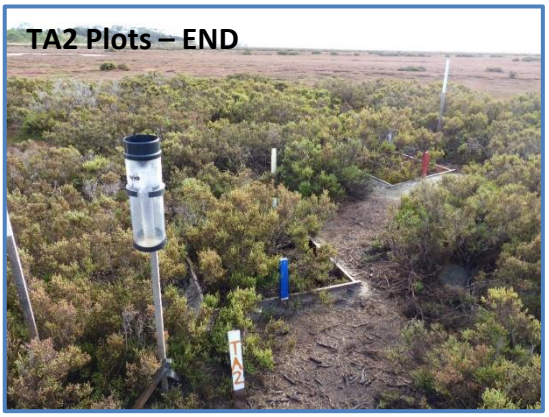

Figure 7A.42: TA2 plots end, view southwest.

Figure 7A.43: TA2 increasing salinity start.

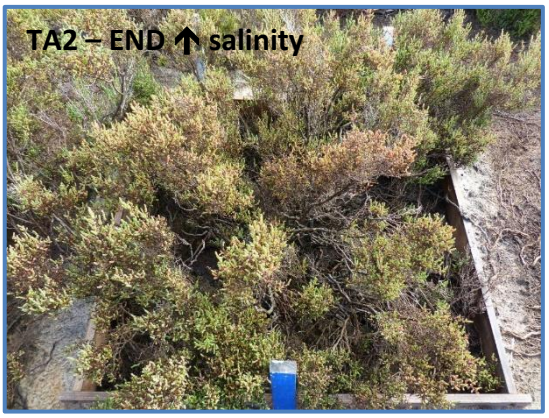

Figure 7A.44: TA2 increasing salinity end.

Figure 7A.45: TA2 decreasing salinity start.

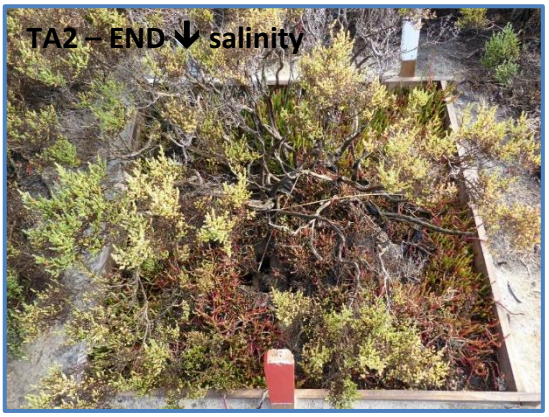

Figure 7A.46: TA2 decreasing salinity end.

Figure 7A.47: TA2 control start.

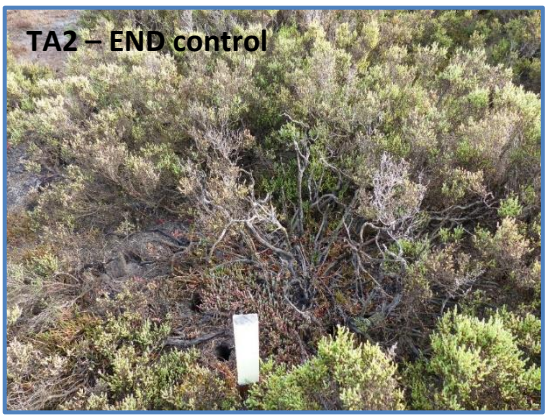

Figure 7A.48: TA2 control end.

Figure 7A.49: GL1 plots start, view northwest.

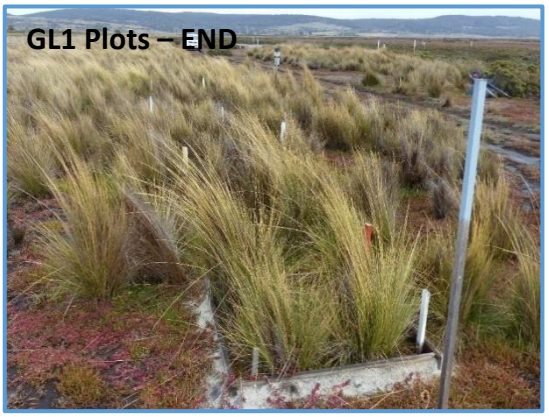

Figure 7A.50: GL1 plots end, view northwest.

Figure 7A.51: GL1 increasing salinity start.

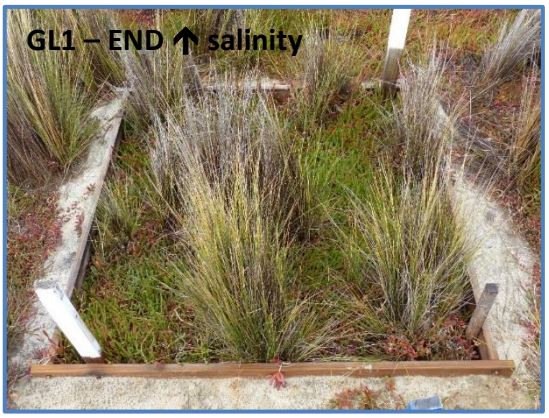

Figure 7A.52: GL1 increasing salinity end.

Figure 7A.53: GL1 decreasing salinity start.

Figure 7A.54: GL1 decreasing salinity end.

Figure 7A.55: GL1 control start.

Figure 7A.56: GL1 control end.

Figure 7A.57: GL2 plots start, view southwest.

Figure 7A.58: GL2 plots end, view southwest.

Figure 7A.59: GL2 increasing salinity start.

Figure 7A.60: GL2 increasing salinity end.

Figure 7A.61: GL2 decreasing salinity start.

Figure 7A.62: GL2 decreasing salinity end.

Figure 7A.63: GL2 control start.

Figure 7A.64: GL2 control end.

Chapter 8

Synthesis and conclusions

Chapter 8: Synthesis and conclusions

It is evident from this study that the Tasmanian coastal saltmarsh community is strongly patterned at the landscape scale. Local plant species diversity can vary widely with numerous instances of multiple species in co-existence contrasting with some mono-specific communities. It is not unusual to find an array of 10-15 species in a local community. The saltmarsh community is noteworthy for its harsh and variable environment. Soil salinity levels can range from brackish to hypersaline, pH levels from acidic to slightly alkaline and moisture levels from total inundation for long periods of time to just once or twice a year. Climate vagaries also contribute to the challenging environmental conditions. Extended periods of strong onshore winds, high rainfall, and cold weather are interspersed with phases of calm, dry and warm conditions. Yet, saltmarsh plants survive and thrive. The persistence and diversity of the saltmarsh flora in this challenging environment are a testament to how well these plants have adapted to this niche.

A deeper understanding of what underlies saltmarsh vegetation patterning and alignment to other natural regionalisations of Tasmania has emerged from this thesis. Particular studies into vegetation classification at a fine scale, edaphic factors and relationship to vegetation communities, soil carbon stores, and plant species resilience were undertaken and conclusions by chapter follow.

Chapter 1 – Natural regionalisation of Tasmania

Coastal saltmarshes are considered a fringing ecosystem that is not readily defined by a simple terrestrial or marine based regionalisation framework. With a focus on natural regionalisations previously applied in Tasmania, candidate regionalisations that might be deemed suitable to characterise coastal saltmarshes were examined. Each of, Interim Biographic Regionalisation of Australia (IBRA), Interim Marine and Coastal Regionalisation of Australia (IMCRA), Bureau of Meteorology coastal (weather) forecast districts, geographical (coastal) regions and an estuarine classification, were considered potential candidates to differentiate vegetation patterning in coastal saltmarshes. Separately, each regionalisation was founded on different physical (e.g. estuary size of catchment, salinity) or biographical (e.g. vegetation community boundaries) characteristics, but all with a human bias. The key question framed from

this chapter centres on the patterns of natural variation within the Tasmanian coastal saltmarsh environment and their alignment to any of the considered pre-existing regionalisations.

Chapter 2 – Defining Tasmanian coastal saltmarshes

Coastal saltmarshes are defined on a national basis under the *Environment Protection and Biodiversity Act 1999* (EPBC Act), and also within a Tasmanian basis by TASVEG, a broad-scale digital map of the State's vegetation. Saltmarshes can be described as either functional (influenced by daily tide rise and fall, e.g. marine inlet), semi-functional (not regularly influenced by daily tide rise and fall, e.g. intermittently closed and open lagoon, spray zone), or non-functional (no current connection to sea, no influence of tides, such as a stranded marsh, previously connected to the sea). Guidelines contained in each of the EPBC Act and TASVEG are mostly complementary, however, they ignore the future prospect of stranded marshes being re-connected to the ocean due to sea-level rise. A modified definition, one that includes stranded marshes, is proposed and employed in this study for the selection of study sites.

Chapter 3 – Vegetation assessment and classification to communities

Broad scale classification used by TASVEG from aerial imagery is suitable for mapping purposes. However, due to a recent surge in Tasmanian coastal saltmarsh research, a vegetation community classification system at a finer scale is clearly needed to provide consistency in current and future saltmarsh studies. Following a state-wide field assessment of 21 sites (involving 110 plots), eight coastal saltmarsh vegetation communities were identified using appropriate analysis following a full examination of established methods of vegetation assessment and hierarchical classification. From this, a vegetation community key was created. The key was subsequently field-tested on 128 plots, leading to refinement and further testing on a further 169 plots, then updated to a final version suitable for use in the field by less skilled observers. Additionally, a new typology was generated consistent with the current broad-scale classification protocols used within TASVEG.

Of 52 plant species collectively identified across all vegetation assessments, 21 (40%) were identified as indicator species for the eight vegetation communities. All groups have a combination of species which characterise the individual community, except for

one which has a single indicator species (*Sarcocornia quinqueflora*). Again, indicator species will make it easier to recognise vegetation communities in the field.

Plant species and vegetation communities were aligned to prevailing climate variables through ordination. Although differences were not great, key plant species (e.g. *Juncus kraussii, S. quinqueflora, Tecticornia arbuscula*) were associated with distinctive climatic sectors of wet + cold, dry + cool, and dry + warm. However, the majority of plant species (e.g. *Austrostipa stipoides, Gahnia filum, Samolus repens, Selliera radicans*) were more associated within a wet + warm sector. Similarly, vegetation communities were mapped to climatic sectors; for example, AGH (graminoids and herbs), AHM (herbs mixed) aligned with wet and warm; AQR (*S. quinqueflora-S. repens*) and ASH (shrubs and herbs) to dry and warm, while AJK (*J. kraussii*) was associated with wet and cold and ASQ (*S. quinqueflora*) aligned with dry and cool.

Vegetation communities were also aligned to five selected coastal regionalisations that were best associated with the terrestrial-marine interface (IBRA, IMCRA, BOM coastal districts, geographic and estuarine classification). Comparisons between regionalisations and between regions within separate regionalisations were unreliable as most vegetation communities showed a preference for Tasmanian east coast-based regions, irrespective of regionalisation type. This may reflect some bias in the large number of field-plots located on the east and southeast coasts. Although a weak alignment was evident, from a field-based view, IMCRA was the better fit to account for vegetation community presence. Further field work, especially targeting the more inaccessible areas of the west, southwest coasts may improve the precision of saltmarsh patterning fit to a regionalisation type.

Chapter 4 – Edaphic factors, climate variables, vegetation communities and plant species

Edaphic factors influence the survival of individual plant species and can be key drivers governing the zonation of vegetation communities. It has been understood that coastal vegetation can be used as a bioindicator of the presence of specific edaphic factors, such as salinity levels. As is evident from the field, many saltmarsh plant species have broadly overlapping edaphic tolerances (e.g. pH, moisture). In recent years, with an increasing focus on conservation and restoration measures, a renewed and expanding

interest in saltmarshes soils has evolved to understand the adaptability of saltmarsh plants to various soil conditions.

Following analysis of a comprehensive soil collection sampled from over 400 plots, it was found that factors such as EC and peat composition (and others, e.g. LOI treatments and pH) were helpful in objectively classifying saltmarsh soils, in this case, to eight groups. Additionally, edaphic factors, individually and in combination, could be used to characterise soil types. Analysis of climate variables based on the eight saltmarsh soil types produced a less clear-cut result. However, temperature and rainfall, could be suitable variables to assist in broadly classifying soil type groups, although this would be quite simplistic as only two outcomes would be fully determined, i.e. wet + cold, and dry + warm. Other climate-determined outcomes might be identified from this, such as, wet + warm.

As soil group indicators, no single plant species was found to be restricted to one particular soil type. Many species inhabit several soil type groups with a few occupying all eight soil types. Consequently, identifying soil type fidelity using plant species is not an option and makes recognition of an individual soil type based on plant species much more difficult in the field. Most vegetation communities were found across all soil types, many in overlapping habitat envelopes, suggesting that soil type may respond to plant species association(s), where, either individual plants species, or a combination of them, locally modify soil conditions to their advantage.

Most saltmarsh soil types were not confined to a particular regionalisation, although it was apparent that the IMCRA regionalisation is a possible candidate for classifying soil types. Additionally, vegetation communities were not confined to individual soil types. The results demonstrated that soil type does not map with vegetation communities, rather that communities appear to be highly adaptable to prevailing soil types and conditions.

Chapter 5 – Saltmarsh carbon store

Coastal saltmarshes are recognised for their role in carbon sequestration and storage, however, reported carbon stock estimates vary widely, due in part to poor precision in calculations. As Australia now includes "blue" carbon (that stored in coastal and marine

ecosystems) in the National Greenhouse Inventory, there is a need to more accurately determine the carbon stocks sequestered around the nation's coastline.

In many cases, estimates of carbon stocks rely on applying a conversion formula to LOI data (the correlation between LOI and dry combustion, an expensive method which determines total carbon) to derive total carbon values. However, conversion formulae are generally site specific, and variation in organic layer depth and vegetation cover can lead to less precise carbon stock estimates. This study determined the validity of some LOI conversions and generated a more suitable conversion based on the dry combustion method for Tasmanian coastal saltmarshes. Then, to improve robustness of the results, more precise LOI conversion formulae were determined for each of the eight vegetation communities. All conversion formulae, whether generic or specific to vegetation community are applicable to Tasmanian coastal saltmarsh soils, though it would be prudent to continue updating and refining the conversion formulae. Estimations of carbon stock in the past have been limited by uncertainties in published estimates. This study shows the importance of precision in carbon estimates through focusing at vegetation community level and deriving more appropriate formulae.

Although Tasmanian coastal saltmarsh carbon stocks (390,000 tonnes, valued at $19.8 million) ranked approximately mid-range to other Australian coastal states, Tasmania's stocks were relatively low. This is due to the shallow soils typical of the State's saltmarshes (mean soil depth less than the 30cm), while other Australian states recorded deeper soils. There were differences measured in carbon stock levels between vegetation communities, however, these differences were not significant. Carbon stock values for similar vegetation communities were dissimilar in different IMCRA regions, suggesting that position in the landscape may play an important role in sequestered carbon.

Chapter 6 – Plant species tolerance

It is clear that most dominant saltmarsh plant species (e.g. *J. kraussii, G. filum, S. radicans, S. quinqueflora*) are present over a wide range of edaphic factors and climate variables, signifying the ability of each species, either individually, or in association with other species, to occupy a wide variety of soil types. This allows for a greater distribution in coastal Tasmanian saltmarshes, in turn adding species richness to many locations.

Three key plant species were identified as suitable pioneers for restoration sites. Evidence on the extent of the range for each individual edaphic factor and climate variable was identified, and from this a workable decision-making tool was devised, accompanied by instructions and examples on usage.

Chapter 7 – Salinity trial

A short field experiment was conducted into likely changes to selected plants (*Disphyma crassifolium*, *S. blackiana, S. quinqueflora* and *T. arbuscula*) and soils of coastal saltmarshes in response to potential sea-level rise and climate change impacts. The study was carried out as an open air, natural environmental field-trial, where no modifications to plots were undertaken other than treatments (either increasing salinity, decreasing salinity or control).

Mean soil pH values showed little change over the course of the study, however, changes in soil EC were observed across treatments. Mean plant species pH values did change across all treatments, though plant species pH changes throughout this study were not a reflection of soil observations. Similar changes in observations were recorded for EC values again across all treatments, although EC concentration in all plant species was far less than that of soils. This is possibly a reflection of each plant species' physiological function, however, this was not measured directly as it fell outside scope of this study. Observations from this study showed that the four targeted plant species would survive both increasing and decreasing salinity impacts, with little to no change in vegetation composition expected within their respective communities. Results also conclude that changes to soil conditions are limited, particularly in respect to pH. Changes to EC levels were noted, though these were not large.

Conclusion

The original question considered whether saltmarsh vegetation patterning was a result of natural regionalisation, and if this fitted any pre-existing regionalisation of Tasmania.

The eight vegetation communities identified in Chapter 3 were also tested for alignment to the five selected coastal regionalisations. However, associations between regions and between regionalisations were unreliable although from a field-based view, IMCRA appeared to be somewhat suitable to record vegetation community presence.

Saltmarsh soil types were not reflective of any regionalisation, although IMCRA regionalisation was deemed as a possible candidate. However, this alignment was resolved as being weak.

Carbon stock levels were different between vegetation communities, but the differences were not significant. Carbon stock values for similar vegetation communities are dissimilar in different regions of all regionalisations including IMCRA, suggesting that there is no association between sequestered carbon volumes and regionalisation.

The strongest alignment of saltmarsh vegetation patterning appears to be with two climate variables, temperature and rainfall. This particularly relates to two climatic sectors, that of wet + cold, and dry + warm, with patterning association also evident between wet + warm, and cool + dry.

What did I achieve?

1. Examined pre-existing natural (IBRA, IMCRA) and geographic regionalisations, weather forecast districts, and an estuarine classification that are useful in characterising the natural Tasmanian coastal landscape;
2. Appraised the current State and National descriptions of coastal saltmarsh and proposed a functional definition useful in the Tasmanian context;
3. Classified coastal saltmarsh vegetation to a fine scale appropriate for localised ecological studies;
4. Prepared, tested and improved a saltmarsh vegetation community key suitable for citizen science community groups;
5. Refined a saltmarsh vegetation community typology that can be directly assimilated into the current Tasmanian classification framework;
6. Determined that vegetation communities do not conform closely to any pre-existing regionalisation of the coastal saltmarsh biophysical environment of Tasmania, although there is a weak alignment to IMCRA;
7. Identified saltmarsh soil types based on edaphic factors (e.g. EC, pH, moisture, bulk density, composition);

8. Determined that soil types do not align closely to saltmarsh vegetation communities, nor generally to pre-existing regionalisations, although there appears minor alignment with IMCRA;
9. Found that different vegetation communities tolerate an extended range of values of individual edaphic factors, with a high degree of overlap between communities;
10. Verified loss on ignition (LOI) procedures and refined a procedure for furnace validity;
11. Established suitable formulae to convert loss on ignition at 550^{o}C values to total carbon (this assumes that soils are non-calcareous) at a generic saltmarsh level and for individual vegetation communities;
12. Calculated the total carbon store and current sequestered value of Tasmanian coastal saltmarshes;
13. Determined that the distribution of saltmarsh carbon stores does not align to any pre-existing regionalisation;
14. Examined the tolerance of key saltmarsh plant species to specific edaphic and climate variables and determined important attributes and their ranges for the species suitable in restoration projects;
15. Tested in a field-based trial, the resilience of four key plant species to increased salinity (sea-level rise) and decreased salinity (increased rainfall); and
16. Determined that although Tasmanian coastal saltmarshes do not conform to any pre-existing regionalisation, they are more aligned to prevailing rainfall and temperature regimes.

Study shortcomings

Some deficiencies and other short-comings have been identified from this study.

Site assessments

Some remote coastal regions (e.g. west and southwest coasts) were not extensively assessed for vegetation and soils due to either inaccessibility, a requirement for long return walks (of up to seven days) or expensive helicopter access. Future assessment would not only complement this study but would provide a more comprehensive appreciation of saltmarsh communities and their make-up in these regions.

Salinity trial

The salinity pulse trial was a short-term study, running for 16 months (with a four month interruption). If the trial had continued even for a further six to twelve months, an improved understanding of plant species survival under these conditions would likely have been realised. Also, the four month gap in treatments may have allowed the soil conditions to return to normalised state, providing a respite to plants from the challenge of the increasing and decreasing salinity pulses.

Suggestions for further study

Coastal saltmarshes are vulnerable ecosystems and under threat in many countries including Australia. More is known and understood now than in the past, however, additional work is required to fully understand and better protect this intriguing environment, the interface between the terrestrial and marine ecosystems.

Study sites

Acknowledged as a shortcoming, the west and south coasts require assessment for the incidence of coastal saltmarsh. It is known that these regions are depauperate of saltmarsh due to extensive unfavourable conditions (e.g. exposed coastline, rocky shores). However, small pockets of saltmarsh were located and assessed in the northern region of the west coast (between Bluff Hill Point and Temma), these previously not identified from aerial imagery. Completion of the assessment would help clarify the issue of vegetation patterning conformity to regionalisation (to the extent it may exist), or any alignment to climatic conditions such as rainfall and temperature.

Saltmarsh soils

There are some steps that should be taken to clarify the relationship between soil type and vegetation communities and regionalisation. These include: identification of tidal amplitude and inundation period; establishment of saltmarsh age from paleo-history; sediment source (terrestrial or marine); elevation above mean tide height; and better understanding of geological and hinterland influences.

Salinity trials

The short-term study identified the need for additional work at a larger scale to fully appreciate the effects of decreasing and increasing salinity on coastal saltmarsh vegetation. The study length should be extended to at least three years to fully

determine plant species, individually and in association with each other, survivability to regular applications of marine and fresh water. Other species should be integrated into the study particularly haline graminoids (e.g. *A. stipoides, G. filum*), which are rarely subjected to tidal inundation. The study should include key species such as *J. kraussii, Samolus repens* and *S. radicans*, these species present in several vegetation communities as well as being present state-wide. Lastly, it would be prudent to conduct the trial across a number sites as this would take into consideration climatic variations (rainfall, solar exposure), soil variations (sand, peat) and aspect (east coast, south coast). The results from this study would provide an improved understanding on plant species endurance to climate change conditions. Additionally, environmental management agencies can either implement mitigation strategies to protect vulnerable species or prepare refugia for continued survival.

Management

Vegetation communities can now be identified to a fine scale and more is now known about Tasmania's saltmarshes following this study. This knowledge can now be applied to locating suitable sites for protection. Using Natural Resource Management (NRM) regionalisation, suitable coastal saltmarshes can be actively managed and conserved. Vegetation and soil assessments should be completed, these forming baselines for future reviews to document change over time.

On-going assessments

This work has provided a seminal baseline study of many coastal saltmarshes in Tasmania and the resulting data is stored and will be readily available for future studies. In respect of good long-term ecological practice, study sites should be revisited on a five-yearly basis to document change in plant species presence/absence and soil observations.

Finally, the following statement by Saintilan (2009) in "Distribution of Australian saltmarsh plants" (*Australian saltmarsh ecology*) is wholeheartedly supported and encouraged:

The generation of a plant species list by Australian estuaries. This would document at fine scale the presence of individual saltmarsh plant species, and further, identify endangered or threatened species within individual estuaries. Information can then be provided to local NRM groups to instigate proper

and coordinated attempts at conservation of coastal saltmarshes threatened plants species and vegetation communities.

This study has documented plant species incidence in many of Tasmanian's estuaries, and its extension to the southern and lower west coasts would finalise Tasmania's contribution to the recommendation from Saintilan.